UPPER SAN PEDRO BASIN ACTIVE MANAGEMENT AREA REVIEW REPORT

March 2005

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CHAPTER 1

INTRODUCTION

1.1 Purpose and Scope of Study

When the legislature adopted the Groundwater Code in 1980, the legislature declared as a public policy that "it is necessary to conserve, protect and allocate the use of groundwater resources of the state and to provide a framework for the comprehensive management and regulation of the withdrawal, transportation, use, conservation and conveyance of rights to use the groundwater in this state." A.R.S. § 45-401. In 1980, the legislature recognized that certain geographic areas of the state, known as active management areas (AMAs), required active management of groundwater. A.R.S. § 45-402(2).

Under A.R.S § 45-412(C), the Arizona Department of Water Resources (Department or ADWR) must "periodically review all areas which are not included within an active management area to determine whether such areas meet any of the criteria for active management areas…" The criteria are specific. The director of ADWR may propose to designate a subsequent AMA if the director determines that any of the following criteria are met: 1) active management practices are necessary to preserve the existing supply of groundwater for future needs; 2) land subsidence or fissuring is endangering property or potential groundwater storage capacity; and 3) use of groundwater is resulting in actual or threatened water quality degradation.

In 2001, ADWR undertook a review of the Upper San Pedro Basin (USP Basin or Basin) to determine if it met the statutory requirements for designation as an AMA. This report reviews the water supply and demand of the USP Basin in the context of the statutory criteria set forth in A.R.S. § 45-412(A), and includes a discussion of whether any of the criteria have been met.

The USP Basin reaches from the international border with Mexico to "The Narrows" north of Benson. This groundwater basin includes two sub-basins, the Allen Flat sub-basin and the Sierra Vista sub-basin. The area proposed for designation may not be smaller than a groundwater basin, except for the regional aquifer systems of northern Arizona. A.R.S. § 45-412(B).

Previously, ADWR conducted a study of the USP Basin and issued a report in 1988 in which ADWR determined that the Basin did not meet the statutory criteria for AMA designation (Putman and others, ADWR 1988). ADWR indicated in the report that it would reassess conditions in the Basin in ten to fifteen years. Since 1988, there has been considerable local, state and federal interest in the water resources of the Sierra Vista area and the San Pedro Riparian National Conservation Area, which is located in the Basin. This interest has resulted in additional hydrologic studies and increased local water management activities.

The study described in this report is an evaluation of whether the conditions of the USP Basin satisfy the statutory criteria of A.R.S. § 45-412. This report contains a description of the current and projected water resources and water demand in the Basin, incorporating new information since the previous review. The report examines historic water use trends, evaluates the groundwater resources of the Basin, and projects impacts of future water use on Basin groundwater supplies. The report includes an evaluation of the incidence of subsidence or fissuring, and of the potential for groundwater quality degradation due to groundwater use. The report further describes and evaluates the impact that AMA practices would have on water use, and includes a summary of findings, the director's determination of whether the Basin should be designated and recommendations. For purposes of this report, groundwater is defined as water withdrawn from a well or water located within an underground aquifer.

Although not required by A.R.S. § 45-412, during the course of preparing this report, ADWR made efforts to keep the affected community informed of its activities. ADWR held two open houses at the inception of the study, which attracted over 180 attendees. ADWR also sent periodic newsletters to more than 300 individuals and made a number of presentations at public meetings.

1.2 Active Management Areas and Irrigation Non-Expansion Areas

Four AMAs were established by the Groundwater Code in 1980. They are the Phoenix, Tucson, Pinal and Prescott AMAs. The Santa Cruz AMA, previously part of the Tucson AMA, was established through legislation in 1994. Due to the area's unique hydrology and water resource management issues, the legislature determined that the Santa Cruz AMA was needed to facilitate binational negotiations for coordinated management of the water resources of the Santa Cruz River. The Code also established two initial irrigation non-expansion areas (INAs), the Douglas and Joseph City INAs. Later, the Harquahala INA was designated by the director of ADWR in 1982. INAs are areas with insufficient groundwater to provide a reasonably safe supply for irrigation. The location of the AMAs and INAs and the Upper San Pedro Basin, are depicted in Figure 1-1.

Water use is regulated by the Groundwater Code in AMAs and INAs. Within AMAs, the Groundwater Code limits groundwater withdrawals, prohibits the development of new irrigated farmland, requires new subdivisions to have long-term dependable supplies (Assured Water Supply Program), and requires measuring and reporting of groundwater withdrawals. Under the Groundwater Code, management goals are established for each AMA, and a series of management plans containing mandatory conservation requirements for industrial, municipal and agricultural water users must be developed by ADWR. Other ADWR programs within AMAs involve conservation assistance, augmentation and monitoring of water supplies. AMA practices are described in detail in Chapter 6. Within INAs, the Groundwater Code restricts the development of new agricultural lands and imposes water measurement and reporting requirements for agricultural users and certain large wells.

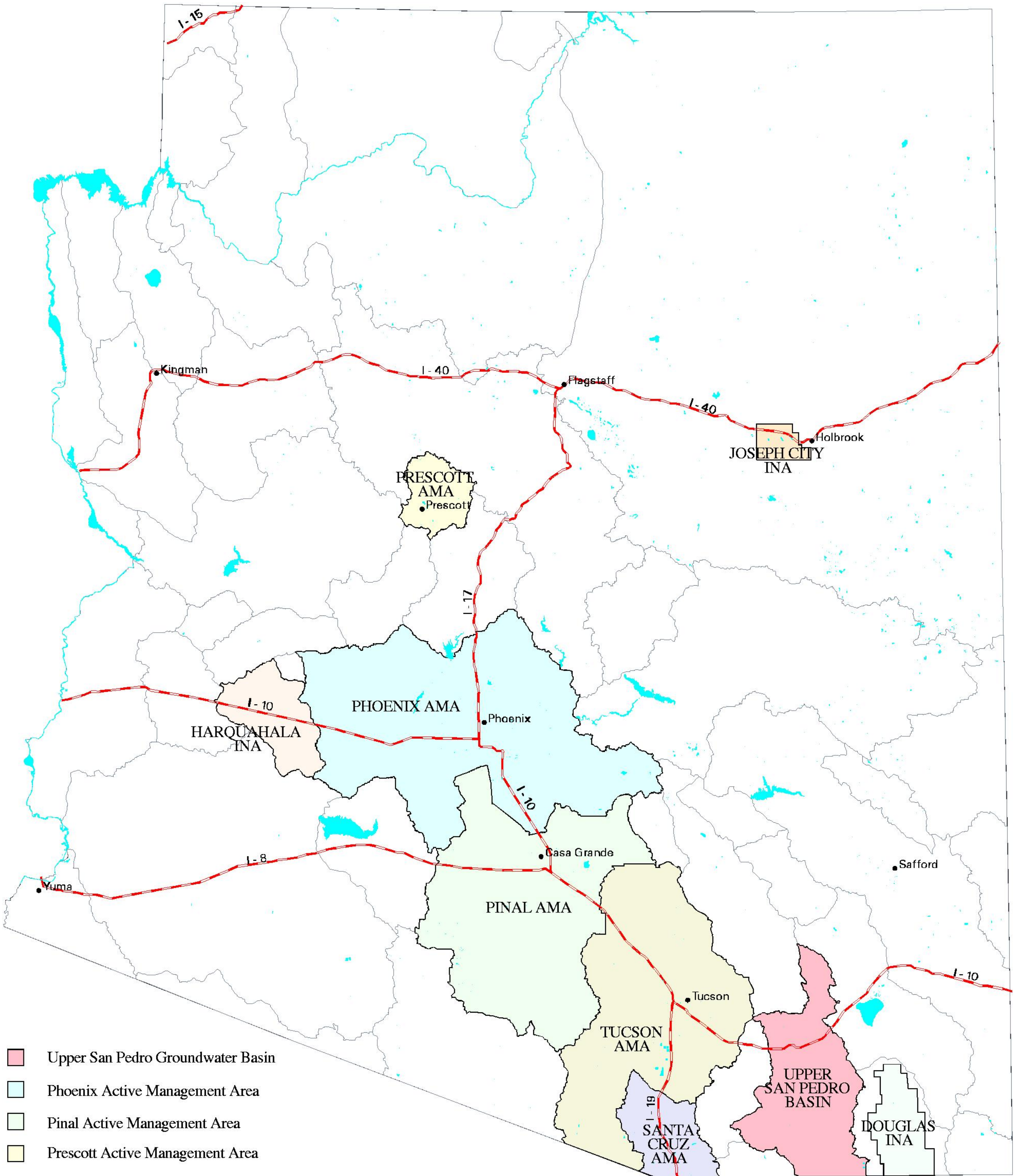

Figure 1 –1

Upper San Pedro Basin

Statewide Location Map

ARIZONA DEPARTMENT OF WATER RESOURCES

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1.3 Subsequent AMA Designation Process

This report evaluates whether the USP Basin should be designated as an AMA under the statutory criteria of A.R.S § 45-412. If the Director determines that the criteria have been satisfied, the director may propose to designate the USP Basin as an AMA and then must follow the public process described in A.R.S § 45-413 and 414. This process involves a public hearing, notice and an order of designation. Under A.R.S. § 45-569, the director would also be required to establish a management goal and adopt a management plan within specified time frames after designation. However, if the Director determines that the statutory criteria of A.R.S § 45-412 have not been satisfied, the procedures described in A.R.S § 45-413, 414 and 569 would not be invoked.

In addition to the process described above, a groundwater basin may be designated as an AMA through legislation, as for the Santa Cruz AMA, or through a locally-initiated petition process as provided in A.R.S. § 45-415. The petition process requires ten percent of the registered voters residing within the boundaries of the proposed AMA to sign a petition to form an AMA, and comply with the procedures described in A.R.S. § 45-415. Once the petition is filed with the predominant county within the proposed AMA, an election is called by the county board of supervisors under the general election laws of the state. To ADWR's knowledge, no petition to designate the USP Basin has been filed under A.R.S. § 45-415.

CHAPTER 2

BASIN OVERVIEW

This Chapter describes the geographic and climatological features of the USP Basin. A brief history of water and land use in the Basin is also discussed. Current and projected water use information is discussed in Chapters 3 and 4. This Chapter also includes a summary of hydrologic studies and water management reports for the Basin. Much of the information presented in this Chapter is from the Department's previous study of the Basin, completed in 1988, with updates.

2.1 Location and Topography

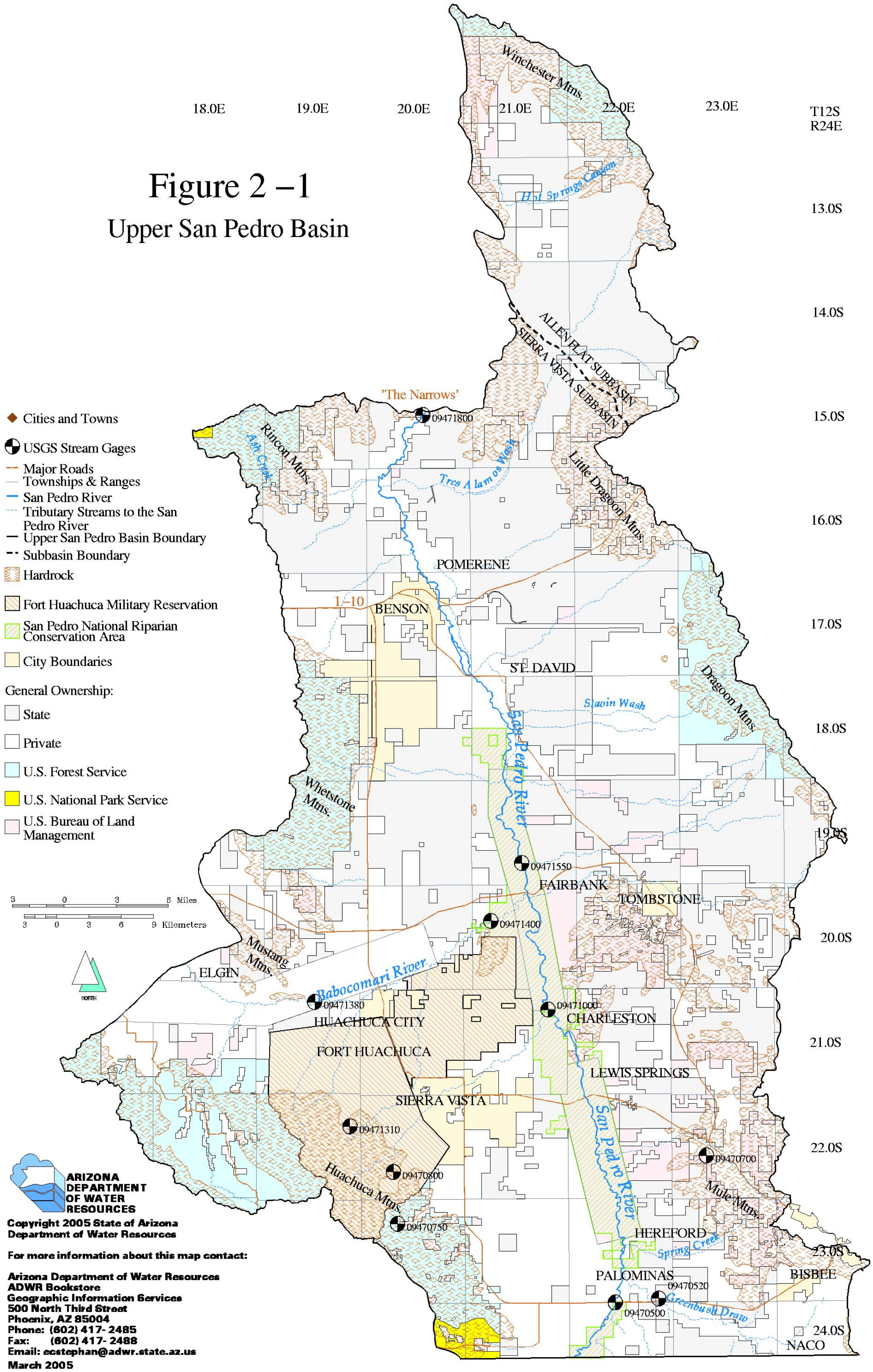
The USP Basin is located in southeastern Arizona about 50 miles southeast of Tucson (Figure 1-1). The Basin boundaries were designated by the Department on July 20, 1982 pursuant to A.R.S. §45-403 and §45-404. The Basin boundaries are defined by ADWR as "the surface watershed of the San Pedro River from the Republic of Mexico downstream to the area referred to as "The Narrows" north of Benson, and in addition, the upper drainage areas of Hot Springs and Kelsey Canyons which enter the San Pedro River north of "The Narrows." The USP Basin is divided into two sub-basins: the Allen Flat sub-basin, which is the upper watersheds of Tres Alamos Wash, Hot Springs and Kelsey Canyons; and the Sierra Vista sub-basin, which is the watershed of the San Pedro River upstream from "The Narrows," exclusive of Upper Tres Alamos Wash" (Arizona Department of Water Resources, 1982). See Figure 2-1 for an overview of the USP Basin.

The Allen Flat sub-basin comprises about 10% of the area of the entire USP Basin. The northern half of Allen Flat is tributary to the Lower San Pedro (LSP) Basin. There are three surface water tributaries that drain the northern half of the Allen Flat sub-basin: Hot Springs Canyon, Bass Canyon and Kelsey Canyon. Tres Alamos Wash drains the southern half of the Allen Flat sub-basin, which is tributary to the USP Basin. Water use in the Allen Flat sub-basin is limited to stock and domestic purposes.

The USP Basin is drained by the San Pedro River. The San Pedro River (River) drains about 2500 square miles at the U.S. Geological Survey (USGS) streamgage near Benson at a location known as "The Narrows" and has a total length of about 90 river miles at that point. About 696 square miles of this drainage area are in Mexico. A few tributaries to the River begin on the southwest slopes of the Huachuca Mountains, in the San Rafael Valley. These tributaries drain about 54 square miles of the United States before entering Mexico in T24S, R19E.

The San Pedro River enters the United States from Mexico, near Palominas, Arizona, in Section 18, T24S, R22E. The River flows northward for about 62 river miles before leaving the USP Basin at the "The Narrows." The River is currently perennial in several

Figure 2 –1
Upper San Pedro Basin



places and is intermittent in other reaches, flowing seasonally in response to climatic and water use variables. The Babocomari River, its major tributary, is also perennial in places, although not at its confluence with the San Pedro River. All other drainages are tributary to the River and, with the exception of a few small streams in the mountains surrounding the Basin, are ephemeral, flowing briefly after significant rainfall events.

Four stream gaging stations have existed at one time or another on the San Pedro River within the USP Basin (Figure 2-1). At the present time, the USGS maintains three stations at Palominas, Charleston, and Tombstone; the gaging station at "The Narrows" has been discontinued. USGS gaging records also exist for seven smaller drainages in the Basin, but for shorter periods of time (Evans, 2001). Appendix A lists the period of record for the 11 stream discharge monitoring sites shown on Figure 2-1.

Several springs are found in consolidated rocks and basin-fill deposits throughout the watershed. In the mountains, springs are recharged from runoff resulting from precipitation and snowmelt. The runoff is intercepted by fractures in the rock where it is transmitted to springs. Springs also occur in areas near the San Pedro River where low conductivity deposits intersect the land surface. Most springs yield several gallons per minute with a few large springs producing up to several hundred gallons per minute.

The mountains that border the Basin range in height from 5,000 to nearly 10,000 feet. These mountains are the Huachuca, Mustang, Whetstone, and Rincon Mountains on the west and the Mule, Dragoon, Little Dragoon, and Winchester Mountains on the east. Much of the valley floor of the Basin is grassland. Elevations along the River range from about 4,200 feet above mean sea level at the International Border to about 3,300 feet above mean sea level at "The Narrows" north of Benson. Biotic communities of the USP Basin vary widely with sub-alpine and montane forests in the higher elevations, evergreen woodlands in the mountains, and zoning to chaparral at lower elevations (Brown, 1982). Desert grasslands and scrub/desert scrub cover a large portion of the valley floor and riparian vegetation exists along much of the San Pedro River and segments of the Babocomari River.

2.2 Climate

Because of its higher elevation, the USP Basin does not experience the extreme desert heat as does much of the rest of the southern part of the state. Summers are moderately warm, with afternoon maximum temperatures normally ranging from the middle 80's to 90°F. Readings above 100°F rarely occur in the higher elevations but are quite frequent in the lower elevations of the USP Basin in July and August. In winter, warm days and cool nights characterize the climate of the USP Basin.

The average annual precipitation ranges from about 11 inches at Benson to 19 inches at Bisbee. The mountains surrounding the Basin receive greater amounts (Sellers and Hill, 1974). Total annual precipitation can vary considerably from year to year. Precipitation in the USP Basin generally occurs during two periods in the year. Precipitation during the summer season of June through October is typically several inches greater than the winter season of November through February (Pool and Coes, 1999). The wet summer season occurs when moist tropical unstable air from the Gulf of Mexico moves northwest into Arizona (Sellers and Hill, 1974; Hereford, 1993). Afternoon and evening showers and thundershowers develop as the warm, moist air is forced up the southern slopes of mountains and is sufficiently cooled. Although these storms are usually of short duration, they are intense enough to occasionally create localized flash flooding. During this "monsoon" season, precipitation is at its maximum on the windward or southeastern side of the mountains. Locations near major mountain ranges are more likely to receive greater amounts of precipitation during these months (Sellers and Hill, 1974). Table 2-1 summarizes temperature and precipitation data for locations in the USP Basin using data from the Western Regional Climate Center (Western Regional Climate Center, 2003).

The winter rainy season in the USP Basin occurs when middle latitude cyclonic storms intensify off the California coast and move east and southward across the western United States. When these frontal systems move far enough south to affect southern Arizona, they may produce several days of gentle rains and moderate winds, and snow on occasions. The snow fraction usually is a relatively insignificant contribution to total annual precipitation in the USP Basin although it may remain visible on the higher mountains for a few days to several weeks (Sellers and Hill, 1974).

Pool and Coes (1999) analyzed precipitation records from four stations in the Basin. Annual precipitation data at Tombstone reflected a decreasing trend of about 1 inch during the period of record, 1897-1997 (Pool and Coes, 1999). Pool and Coes (1999) noted that long-term winter precipitation amounts showed no decline; summer precipitation showed a decrease of about 1 inch over the period of record, similar to the annual data.

High temperatures and low humidity result in high evaporation rates in the Basin. Estimated lake evaporation rates in the USP Basin are about 60-65 inches per year (Arizona State University, 1975).

Table 2-1. Summary of Annual Precipitation and Temperature Data at Weather Observation Stations in the USP Basin.

Station	**Period of Record**	**Elevation (ft. abv. mean sea level)**	**Avg. Annual Temp. Min**	**Max. (°F)**	**Avg. Annual Precipitation (in.)**
Benson	1894-1975	3,590	45	80	11.3
Bisbee	1892-1985	5,300	49	74	18.6
Fort Huachuca	1900-1981	4,664	49	75	15.6
Sierra Vista	1982-2002	4,623	49	77	14.7
Tombstone	1893-2002	4,610	49	77	13.9

(Data from Western Regional Climate Center, 2003; www.wrcc.dri.edu)

2.3 Brief History of Water and Land Use

Water is used in the USP Basin for a variety of purposes, including municipal, industrial, military and domestic uses, agricultural and stock use, and by wildlife and riparian systems primarily associated with the San Pedro and Babocomari Rivers. Discussed below is historical information concerning water and land use in the USP Basin. This information is presented for background purposes.

The earliest records of uses of water were made by the Spanish exploratory expeditions of the 1600 and 1700s. The Spanish noted a number of Sobaipuri villages associated with farming and also noted a river with a somewhat different character than found today. Villages at Quiburi, downstream of the mouth of the Babocomari River, and a number of other places were noted and native population was estimated at about 2,000 inhabitants in the area now known as the USP Basin. In addition, the Spanish noted extensive grasslands and a river of cienegas with generally broad and un-incised banks, few trees, and many beaver and fish. Direct diversion of water from the River into canals for irrigation was common (Officer, 1987; Arizona State Land Department, 1997).

As the Spanish began to expand their influence into the Basin, so did the Apache Indians (Officer, 1987). Skirmishes between the Sobaipuri, Apache, and Spanish kept the Basin on the Spanish frontier. The Spanish presidio at Terranate near the site of Fairbank represented one attempt to protect settlers and the Sobaipuri Indians during the mid-1770s. Its commander abandoned this outpost in 1779, citing pressure by the Apaches as the reason for abandonment (Officer, 1987). In 1821, Mexico won its independence from Spain and settlement attempts continued, as did documentation of conditions in the Basin. Mexican land grants were made in 1827, 1828, and 1832 to Mexican settlers in the Basin (Officer, 1987).

American mountain men were the first to document the conditions in the Basin in English, and noted many wild cattle in the Basin and many beaver as well. James Ohio Pattie referred to the San Pedro River as the “Beaver River” and trapped along its length in 1824-25 and 1827-28 (Pattie, 1834, in Officer, 1987). Pattie noted the absence of large trees along the banks of the River and its generally un-incised nature, although several later travelers noted areas where the riverbanks were high enough and steep enough to prevent wagons from crossing (Arizona State Land Department, 1997). Abundant “trout” were often noted. These are thought to be Colorado squawfish, now absent from the river system (Arizona State Land Department, 1997). Settlers from Tucson, escorted by Mexican soldiers for protection from the Apaches, diverted water from the San Pedro to farmland near the confluence of Tres Alamos Wash and the River (Arizona State Land Department, 1997).

The Mexican-American War of 1843-46 brought additional documentation by military parties passing through the Basin. In 1854 the Gadsden Purchase made the USP Basin part of the United States. The Basin was transited by surveyors for roads and rail lines in the 1850’s and 1860s, and Benson was established as a railroad town in 1857 (Arizona State Land Department, 1997). Discovery of lead, copper, and silver at Bisbee and

Tombstone brought additional settlement and the towns of Charleston and Fairbank were founded as mill towns in the early 1880s. Railroads were built to support the mines. Extensive woodcutting for timbers for mine shafts, railroad ties, housing, and cooking caused a great change in the vegetation of the Basin about this time (Arizona State Land Department, 1997).

Farming and ranching was again established in the 1860's through the 1880's, and the first use of artesian wells in Arizona occurred in the St. David area in 1887 (Bryan and others, 1934). In 1881, a post office was established at St. David.

The latest stream entrenchment episode of the San Pedro River began in 1883 near Charleston. By the early 1890s entrenchment had spread along the length of the River (Arizona State Land Department, 1997). Waters and Haynes (2001) noted that entrenchment and depositional episodes were common over the last 10,000 years. During the 1950’s, the San Pedro River channel began to stabilize and deposition of sediment was relatively equal to erosion of sediments (Hereford, 1993).

By 1899, about 3,500 acres of land were estimated to be under cultivation in the Upper and Lower San Pedro Basins (Arizona Department of Water Resources, 1991a). Benson and Bisbee were the population centers of the Basin, and although part of Bisbee lies just outside the Basin boundary, its supply wells are within the Basin. Bryan and others (1934) list more than 4,200 acres under cultivation in the upper Basin in that year. Of that, about 3,300 acres were listed as being irrigated by diversions of the St. David Ditch and the Benson Ditch. About 650 acres of alfalfa were irrigated on the Warren Ranch near Bisbee using groundwater pumped from the mines. Bryan and others listed small acreages in various parts of the USP Basin that were irrigated using pumped wells. They also discussed the irrigation of more substantial plots of land near Palominas and Hereford using canal diversions and flowing wells, but did not quantify the land under cultivation. They also noted that there was no use of pumped wells for irrigation in the St. David-Pomerene area, but that flowing wells supplied supplemental irrigation water. Pumped wells were used mostly as a supply for households and gardens (Bryan and others, 1934).

Heindl (1952) listed 5,600 acres under cultivation in that year. About 4,000 acres were in the northern part of the USP Basin, and 1,600 acres in the southern portion. He estimated agricultural demand at 17,000 acre-feet per year, using a demand rate of 3 acre-feet per acre of cropland. He also estimated that 15% of the water applied to the land returned to the aquifer as recharge, reducing agricultural use to 14,500 acre-feet per year. Domestic and stock use was estimated at 1,500 acre-feet per year, and military and municipal demand at 2,250 acre-feet per year. Bisbee was not included in his demand figures.

The quality and quantity of data on estimated water use increased after 1966. Systematic data collection on water use began in 1966 by the USGS. Prior to this time, data on water use were not collected in a regular or comprehensive manner. Important sources of data include the Arizona Corporation Commission, the USGS, records volunteered by water companies in the Basin, and the Department's Hydrologic Survey Report for the San Pedro River Watershed (Arizona Department of Water Resources, 1991a).

Roeske and Werrell (1973) estimated a total Basin water use of about 35,400 acre-feet in 1968. They estimated that 22,100 acre-feet were used for agriculture, 6,600 acre-feet for mining and industrial purposes, and 6,600 acre-feet for municipal and other purposes. Their estimate did not include riparian uses.

The USGS estimated that about 31,000 acre-feet of water were pumped in the USP Basin in 1985 (U.S. Geological Survey, 1986). About 20,500 acre-feet were used for agricultural purposes, primarily in the northern part of the USP Basin. About 10,200 acre-feet were used for municipal, industrial, military, and domestic purposes, primarily in the southern part of the USP Basin.

Based on aerial photos, Putman and others (1988) estimated that about 7,150 acres were farmed in 1977, and about 9,800 acres in the 1983-85 time period in the Sierra Vista sub-basin. Use of both surface water and groundwater by riparian plants and riverine evaporation was estimated to be about 31,000 acre-feet per year for the entire USP Basin (Putman and others, 1988). Groundwater modeling efforts and other recent studies indicate that about half of the riparian use is supplied by groundwater and the other half by surface flows of the Babocomari and San Pedro Rivers (Corell and others, 1996; Scott and others, 1996; Chehbouni and others, 2000). This is further discussed in the section on groundwater budget outflows in Chapter 3.

In the Sierra Vista sub-basin, non-agricultural groundwater use was estimated to be about 11,000 acre-feet (Putman and others, 1988). The Department used an estimate of 11,000 acre-feet of groundwater pumpage for 1991 in a later report on the southern half of the Sierra Vista sub-basin (Corell and others, 1996). The 1996 report documented development of a groundwater model used to evaluate the impacts of groundwater withdrawals on the groundwater system. The model study area did not include Benson or Tombstone, the area along the upper Babocomari River west of Fort Huachuca, the St. David and Pomerene farming areas, or the Allen Flat sub-basin.

Groundwater use in the Basin has decreased substantially since the mid-1980's, due to extensive conservation efforts by Fort Huachuca and the City of Sierra Vista. Also, farmlands in the southern and central parts of the Basin have been retired from irrigation by the U.S. Bureau of Land Management (BLM) for the San Pedro Riparian National Conservation Area (SPRNCA), which was created in 1988 by Congress. Farming has also been reduced substantially in the St. David, Benson and Pomerene areas from levels found in the 1980's (see Chapter 4 of this report).

Since 1988, additional information regarding land and water uses within the USP Basin have been developed by not only the Department, but also by other state agencies, federal entities, universities, environmental groups and consortiums. This report discusses many of those studies, which also include data and analyses regarding groundwater conditions in the USP Basin.

2.4 Basin Hydrologic Studies and Water Management Reports

The USP Basin has been well studied by many state and federal agencies, including the Arizona Department of Water Resources, U.S. Geological Survey, U.S. Department of Agriculture and U.S. Bureau of Land Management. In addition, the University of Arizona and several other universities, environmental groups, and the Center for Environmental Cooperation (CEC) have conducted scientific studies of the Basin. Many other studies are in progress as of the date of this report. Scientific study has concentrated on the southern portion of the Sierra Vista sub-basin because this area is where the highest concentration of people and water use occurs in the Basin. One of the tasks of this report has been to incorporate scientific findings to date in order to make the most scientifically sound information available to Department management and the public.

Many geologists and hydrologists have described the groundwater system of the USP Basin over the last 100 years. Lee (1905) briefly described the Basin in a report to Congress. Bryan, Smith and Waring of the USGS provided an overview of the Basin in 1934 (Bryan and others, 1934), discussing water use, downcutting of the floodplain, and the general hydrology. Heindl, in 1952, also discussed the general hydrology of the Basin and provided a regional groundwater level map. Brown and others, in 1966, discussed the geology in more detail, followed by Roeske and Werrell in 1973. The USGS provided a more detailed map of water levels, depths to water, changes in specific wells, and water quality data in 1978 (Koniezcki, 1980). In 1982, the USGS published a report on the regional hydrology of the Basin that included a groundwater model (Freethey, 1982). This model was used to evaluate the effects of groundwater pumpage in the southern half of the Basin and was used by the Department in its 1988 evaluation of the Basin for AMA status. (Putman and others, 1988).

The Department published its Hydrographic Survey Report (HSR) for the San Pedro River Watershed in 1991 in support of the general adjudication of the Gila River System and Source (Arizona Department of Water Resources, 1991a). The HSR includes extensive data on the historic extent of farming and other water uses in the Basin and the use of water by various individuals and sectors.

In 1992, the University of Arizona completed a groundwater model that was based on the 1982 USGS model, but that included a more sophisticated streamflow analysis (Vionnet and Maddock, 1992). The Department published a model in 1996 that was based on re-analysis of available geologic and hydrologic data, and included a larger area of the Basin within its boundaries than did the Freethey model (Corell and others, 1996). Both models deal only with the southern portion of the Sierra Vista sub-basin and not with the Basin north of Fairbank. Several Master's theses that utilize groundwater models have dealt with portions of the San Pedro Basin north of Fairbank, including Jahnke (1994). Water and Environmental Systems Technology, Inc. (W&EST) has also done several groundwater models on the Upper and Lower San Pedro Basin in support of water rights litigation by the Gila River Indian Community (W&EST, 1996). Goode and Maddock

(2000) published a model of the entire USP Basin that combines the model created by Vionnet and Maddock (1992) and the model created by Jahnke (1994). This model has also been used to study future effects on the groundwater system of different growth/development scenarios. Model results are discussed in Chapter 5 of this report.

The USGS and a consortium of federal agencies and universities, and agencies from the United States, France, Mexico, and other countries are engaged in ongoing and recently completed studies. An overview of these recent efforts can be found in Pool and Coes (1999) and in Goodrich and others (1999). The Commission for Environmental Cooperation completed a report in 1999 that listed a number of management options for the Basin (Commission for Environmental Cooperation, 1999).

Other important regional studies of the Basin include an evaluation of the hydrology of the Benson area by Fluid Solutions (2000), a Master's thesis set in the Allen Flat sub-basin (Burtell, 1989), and a Master's thesis on the Babocomari River (Schwartzman, 1990). In 1997, ADWR produced a Hydrologic Map Series (HMS) of the USP Basin showing water levels and water quality conditions in the USP Basin (Barnes, 1997). Another HMS has been produced by ADWR showing 2001-2002 conditions in the USP Basin (Barnes and Putman, 2004). More studies exist that deal with specific local areas of the Basin and these studies are referenced in this report as necessary.

In cooperation with the Upper San Pedro Partnership (USPP), a research team was recently formed to study the SPRNCA. The team consisted of faculty and students from Arizona State University, the University of Arizona, and the University of Wyoming; and staff of the U.S. Department of Agriculture-Agricultural Research Service and the U.S. Geological Survey. The study had three primary goals – determine the water needs of riparian vegetation within SPRNCA to ensure its long-term ecological integrity; quantify the current water use by this vegetation; and, determine the source of water consumed by the vegetation. The research team collected and analyzed field data from 2000 through 2003 and summarized their findings in three, separate reports. The reports were released in draft form in March 2004 and should be finalized by early 2005 (Scott and others, 2004, in preparation).

In 2004, Congress passed the National Defense Authorization Act for Fiscal Year 2004 (Public Law 108-136). Section 321 of this act directs the Secretary of the Interior to "prepare in consultation with the Secretary of Agriculture and the Secretary of Defense and in cooperation with the other members of the [Upper San Pedro] Partnership, a report on water use management and conservation measures that have been implemented and are needed to restore and maintain the sustainable yield of the regional aquifer [in the Sierra Vista Subwatershed] by and after September 30, 2011". The "321 Report" is to be prepared annually beginning in 2004 and ending in 2011, with the first report due to Congress on or before December 31, 2004. Included in the 2004 report is a description of the USP Basin and the Sierra Vista Subwatershed; a definition for sustainable yield; discussion of annual net withdrawals and recharge in the subwatershed; a description of water management measures to achieve sustainability; and a listing of monitoring and reporting requirements (U.S. Geological Survey, 2004a).

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CHAPTER 3

HYDROLOGY

In order to determine whether the statutory criteria for designating an AMA for the USP Basin have been satisfied, the Department evaluated hydrologic and water use information for the entire USP Basin, as well as information specifically related to the Sierra Vista sub-basin and the Allen Flat sub-basin. For this evaluation the Department examined information relating to the existing supply of groundwater available for future needs, land subsidence and water quality. These topics are discussed below.

3.1 Existing Groundwater Supplies For Future Needs

To determine the need for an AMA, the first factor that the director of ADWR must consider is whether "active management area practices are necessary to preserve the existing supply of groundwater for future needs." A.R.S. § 45-412(A.1). In order to help make this determination, the Department evaluated geologic data, the groundwater system, historic and current groundwater levels, groundwater elevation changes, and groundwater in storage. From these data, the Department developed a groundwater budget for the USP Basin.

3.1.1 Geology

Sierra Vista Sub-Basin

General Basin geology is well described by Brown and others (1966). The Sierra Vista sub-basin lies between the Huachuca and Whetstone Mountains on the west and the Mule and Dragoon Mountains on the east (Brown and others 1966). Figure 3-1 provides an overview of the surficial extent of geologic units in the USP Basin.

The Sierra Vista sub-basin is composed of several deep troughs filled with alluvial material. The bottom and sides of the sub-basin are formed by bedrock such as granite, sandstone, and limestone. These rocks lie at or near the land surface near the mountains and at depths of up to 5,500 feet below land surface in the middle of the Basin (Drewes, 1980; Halverson, 1984; Gettings and Houser, 2000). Gettings and Houser (2000) expanded on a gravity survey originally completed by Halverson (1984). The Gettings and Houser study discusses three relatively deep alluvial troughs in the Basin. Two of the structural troughs are located west of the San Pedro River and are north and south of Sierra Vista, respectively. The third trough is east of the San Pedro River and northwest of Tombstone. A fourth trough may exist north of Benson, but the detailed study by Gettings and Houser (2000) ends in this area, making the existence of the trough speculative. An earlier study by Oppenheimer and Sumner (1980) shows the inferred depth of alluvial fill north of Pomerene.

Figure 3-2 shows the regional extent of the aquifer and the depths to bedrock in the Sierra Vista sub-basin. It also shows the Department's informal division of the Sierra Vista sub-basin into the Sierra Vista sub-area and the Benson sub-area. These sub-areas are discussed further in section 3.1.6. Gettings and Houser (2000) found a more shallow area of hardrock extending between the troughs north and south of Sierra Vista. This east-west trending shallow area of hardrock under Fort Huachuca, Sierra Vista, and Charleston separates the two deep troughs to the north and south. Bedrock is found at relatively shallow depths of 200-500 feet below land surface along this line. This study also found that much of the area of the Basin under the San Pedro River between Lewis Springs and Benson was underlain by very shallow alluvium, on the order of 150 feet to 400 feet in thickness. The Gettings and Houser study is notable because it defines the depth of alluvial fill as much more shallow than prior studies, effectively reducing the estimated extent of the aquifer and the aquifer's total groundwater storage volume.

The alluvial fill of the Sierra Vista sub-basin can be divided into four general units. Pool and Coes (1999) provide a good overview of the four units. The lowermost unit is the Pantano (?) Formation, which is a consolidated conglomerate that locally supplies water to wells near Sierra Vista. The Pantano Formation yields water to wells by means of fractures in the conglomerate (secondary permeability). The Pantano (?) Formation is of several ages and is not identical in its origins to the Pantano Formation of the Tucson Basin (Gettings and Houser, 2000). This unit is locally important as an aquifer, but has not been explored as a source of water regionally. The thickness of the Pantano (?) Formation ranges from 0 to several thousand feet. It outcrops on the surface to the northwest of Fort Huachuca and is found at depths of 2,000 feet or more in the alluvial troughs of the Basin. The extent of the Pantano (?) Formation in the northern portion of the Sierra Vista sub-basin is not well understood. Gettings and Houser (2000) state that the Pantano (?) Formation does not outcrop north of Huachuca City and may not be present north of there. The Pantano (?) Formation forms part, but not all, of the Pre-basin and range sedimentary rocks (Tsm) shown in Figure 3-1.

The Pantano (?) Formation is overlain by the lower and upper basin-fill units (Figure 3-3). The lower basin-fill is the principal aquifer in much of the Basin (Pool and Coes, 1999). It is more consolidated than the upper basin-fill and contains a number of clay and silt lenses that may cause localized confining conditions to exist. The upper basin-fill is less consolidated and contains more sand and gravels, but is not saturated in some areas of the Basin. The estimated depth of the Pantano (?)-alluvium contact from Gettings and Houser (2000), together with the water levels in wells in some parts of the Basin, indicate that the upper and lower basin-fill units are not always saturated, and that water is being withdrawn from an underlying unit such as the Pantano (?) Formation. One such area is north of Tombstone and east of St. David.

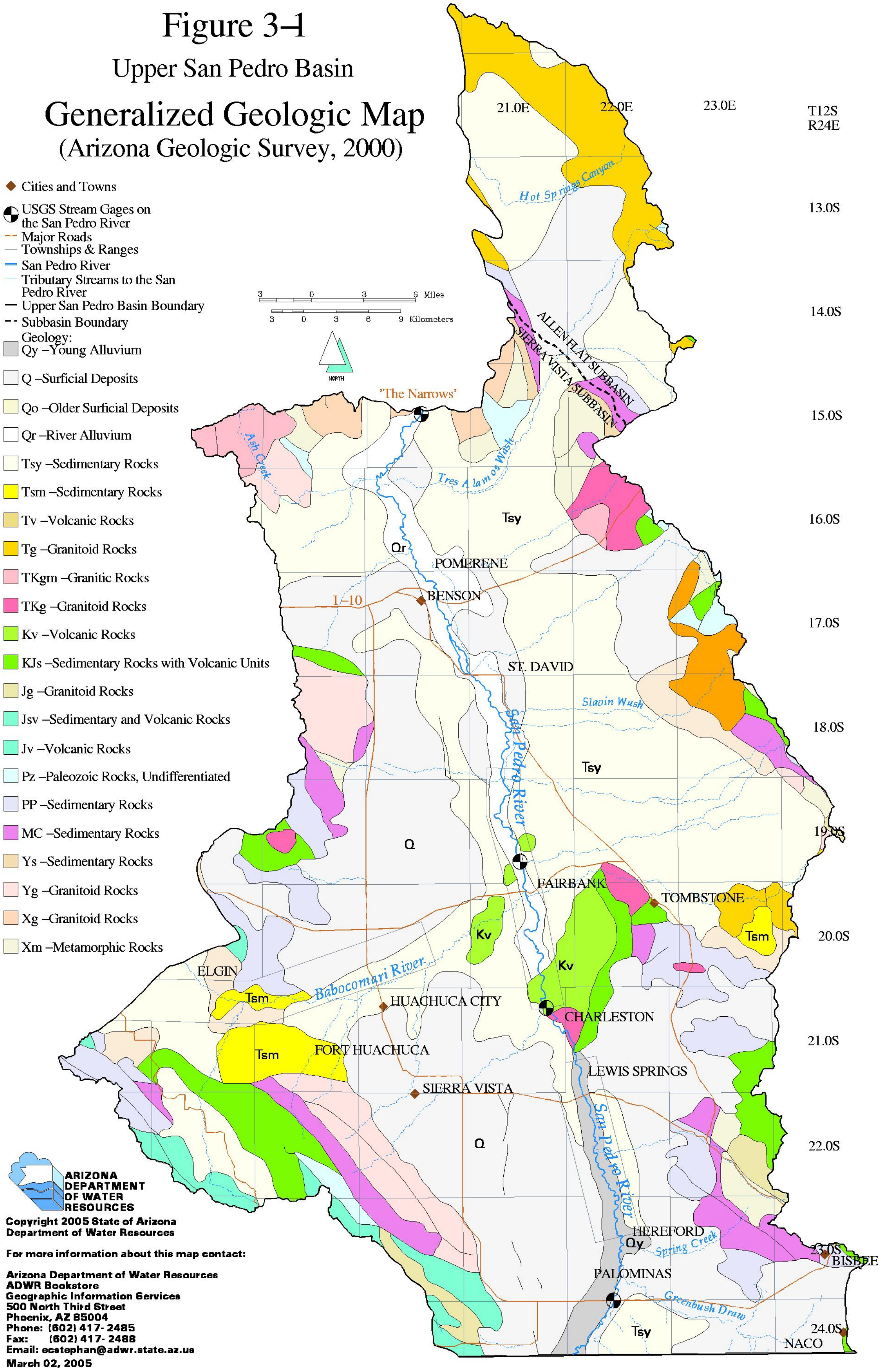
The uppermost alluvial unit is the floodplain alluvium of the San Pedro and Babocomari Rivers. This unit is relatively thin and narrow and consists of unconsolidated gravels, sands, and silt deposited by flood flows of the river systems. It is also referred to as the recent alluvium or Quaternary alluvium. This unit is generally less than 50 feet thick and

Figure 3-1

Upper San Pedro Basin

Generalized Geologic Map

(Arizona Geologic Survey, 2000)



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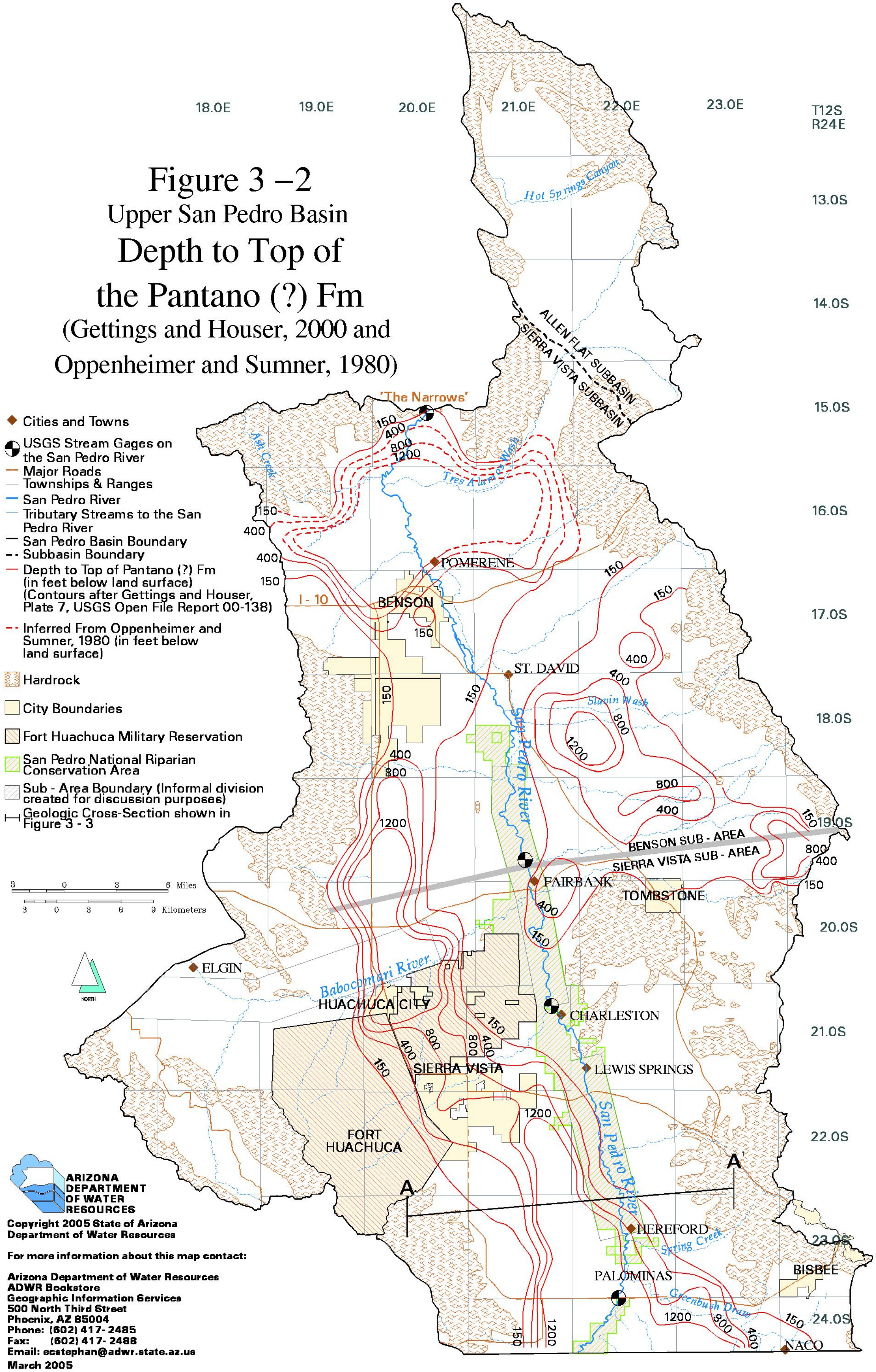
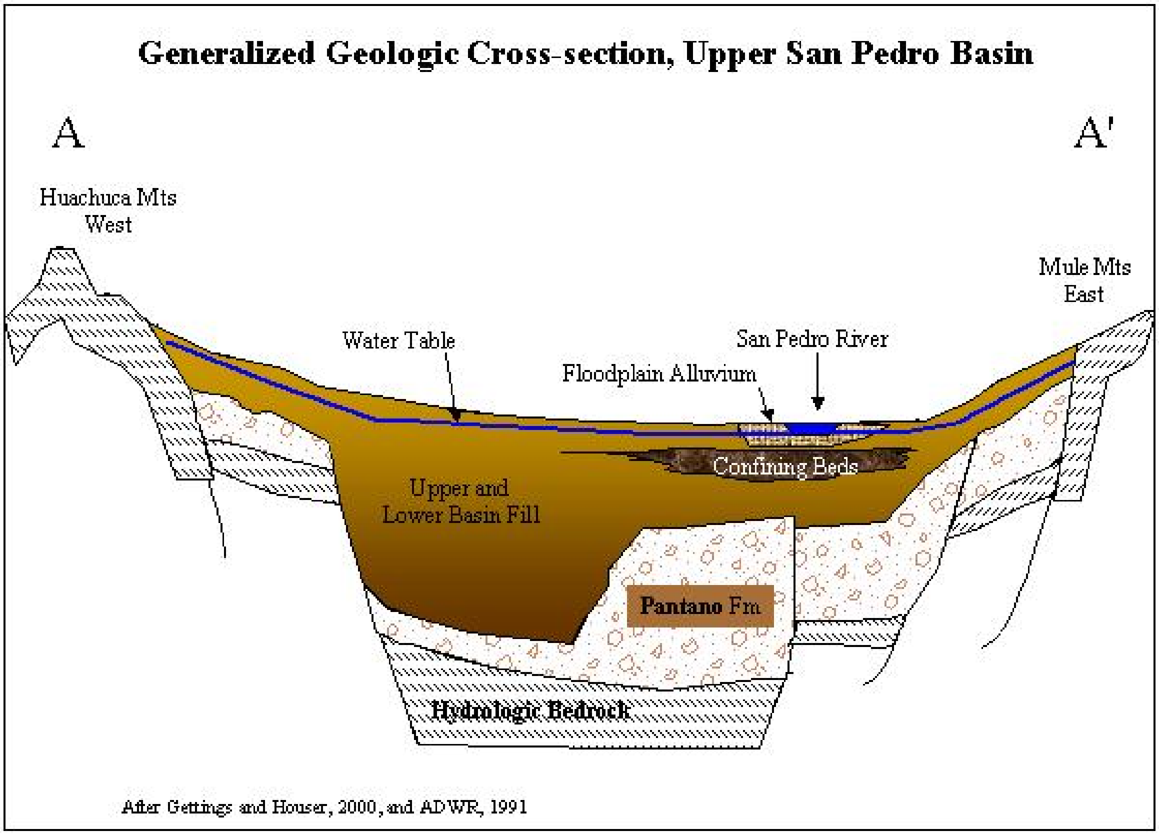


Figure 3 –2
Upper San Pedro Basin
Depth to Top of the Pantano (?) Fm
(Gettings and Houser, 2000 and Oppenheimer and Sumner, 1980)

Figure 3-3. Generalized Geologic Cross-section, Upper San Pedro Basin.



ranges in width from a few feet to about two miles (Drewes, 1980; Putman and others, 1988; Pool and Coes, 1999; Arizona Geologic Survey, 2000). It is saturated near the perennial and intermittent portions of the San Pedro and Babocomari Rivers and serves as a prolific but limited aquifer.

Allen Flat Sub-Basin

The Allen Flat sub-basin is a small, intermontane sub-basin located in the northeast portion of the USP Basin (Figure 2-1). Allen Flat covers an area of approximately 125 square miles, roughly 25 miles in length and 5 miles wide (Burtell, 1989). The area is surrounded by several mountain ranges and small hills including the Winchester Mountains to the northeast, the Galiuro Mountains to the northwest, the Johnny Lyon Hills to the southwest, the Little Dragoon Mountains to the south, and the Steele and Gunnison Hills to the southeast. These mountain ranges consist of granitic igneous and metamorphic rocks, volcanic rocks, and indurated sedimentary rocks which include limestone, sandstone, shale, conglomerate and some quartzite (Putman and others, 1988). The majority of the Basin contains basin-fill that ranges from 550 to over 1,180 feet in thickness (Burtell, 1989); the maximum depth of fill is unknown. Floodplain alluvium composed of sand, gravel and some silt generally occurs along or near washes and is usually less than 25 feet in depth (Burtell, 1989).

3.1.2. Groundwater System

Sierra Vista Sub-Basin

There are two primary aquifers in the Sierra Vista sub-basin. They are the regional aquifer and the floodplain aquifer. The Pantano (?) Formation also serves to supply wells locally in the Sierra Vista area, but may not be regionally present (Pool and Coes, 1999; Gettings and Houser, 2000). Hydraulic communication between the upper and lower basin-fill units is generally good and water levels from wells in either aquifer unit are contoured together in many areas to produce groundwater level maps for the Basin. Confined conditions exist near Palominas, Hereford, and more extensively near Benson and St. David, as discussed below. The floodplain aquifer is also in good lateral hydraulic communication with the regional aquifer, and water levels in the floodplain aquifer are contoured as an extension of the regional water levels (see Figures 3-4 thru 3-9).

Several areas of confined aquifer conditions occur along the San Pedro River near St. David, Hereford and Palominas (Bryan and others, 1934; Roeske and Werrell, 1973; Konieczki, 1980; Pool and Coes, 1999). Pool and Coes (1999) described the occurrence of confined conditions as much greater than had been reported in previous studies. However, there are insufficient data to produce separate water-level maps for these confined areas. The hydraulic head in these areas has been depleted over time and the water levels in wells in confined areas may no longer rise to land surface (Roeske and Werrell, 1973). Artesian conditions were important in the early agricultural development of the St. David-Benson area and in the area north of Benson. Artesian conditions continue to support modest groundwater discharges to wells in these areas. Aquifer pressures in the confined aquifer of the Palominas-Hereford area were insufficient for large-scale irrigation (Bryan and others, 1934).

Recently the presence of a limestone aquifer in the Whetstone Mountains has been emphasized by the discovery of Kartchner Caverns, now a world-renowned state park. The cavern is a "live" or wet cave. Limestone caves also exist in the Huachuca Mountains in the southern part of the sub-basin, although they are not as extensive as Kartchner Caverns. A publication by Graf (1999) discusses the hydrology of the cave. There are three aquifer systems within the boundaries of Kartchner Caverns State Park. The southeastern part of the Park overlies the regional alluvial aquifer. The water level in a well within park boundaries that is completed in the alluvial aquifer shows that the water level in the cavern is about 700 feet higher than that of the regional aquifer. This indicates a large degree of hydraulic separation between the regional aquifer and the limestone aquifer (Graf, 1999). A pediment aquifer exists in the southwestern part of the Park. This aquifer consists of a thin layer of granitic sediment that yields water poorly to wells. The water in this aquifer is about 60 feet higher than the known bottom of the cavern. The third aquifer is the limestone formation containing the cavern. This hydrologic system is recharged by infiltration from ephemeral washes that lie over the limestone block (Graf, 1999).

Allen Flat Sub-Basin

The groundwater system of the Allen Flat sub-basin is principally recharged along mountain fronts. An apparent northeast-southwest trending groundwater divide separates the sub-basin's groundwater flow system into several portions; groundwater exits the sub-basin by flowing to the west, the south and to the southwest (see Figure 3-8). North of the groundwater divide, the groundwater system discharges generally westward to Kelsey Canyon and Hot Springs Canyon, which are tributary to the San Pedro River north of "The Narrows" in the Lower San Pedro Basin. South of the divide, groundwater flows to the south, paralleling Tres Alamos Wash, into the Sierra Vista sub-basin. Small amounts of groundwater may also flow southeast to the Willcox Playa area.

3.1.3 Historic and Current Groundwater Levels

Groundwater elevation maps for 1940, 1961, 1968, 1978, 1990, and 2001 are presented in Figures 3-4 through 3-10, and discussed in this section. Regional groundwater level changes and changes in specific wells are also discussed in section 3.1.4. These data were collected primarily by the USGS until about 1980, and by ADWR after that time.

Sierra Vista Sub-Basin

For the portion of the Sierra Vista sub-basin south of Fairbank, Freethey (1982) developed a groundwater-level map representing the year 1940. This map is considered by several authors to represent a pre-development groundwater system (Freethey, 1982; Putman and others, 1988; Vionnet and Maddock, 1992; Corell and others, 1996). A pre-development groundwater system is one in which groundwater pumping has not existed or has been small enough that the groundwater flow directions and flow rates and the amount of groundwater in storage has not appreciably changed from its undisturbed, equilibrium state. The 1940 map is based on only a few data points and necessarily includes some professional judgment. This map was developed as a starting point for groundwater models and covers only the area that was modeled. Freethey's 1940 map was based on water levels in several dozen wells from the early 1950's and on annual water-level change rates. Freethey extrapolated water levels backward for a dozen years to arrive at a probable 1940 water level, and then contoured the water levels to produce a water-level elevation map for 1940 (Freethey, 1982). Corell and others (1996) used a similar procedure to develop a 1940 map for their groundwater model (see Figure 3-4).

The 1940 maps of Freethey (1982) and Corell and others (1996) are similar in regional pattern. They show a groundwater flow system that receives most of its recharge near the mountain fronts and that discharges groundwater to the San Pedro River in the center of the Basin. Groundwater flow is from the mountain fronts on either side of the Basin toward the Basin center (see Figure 3-4). Groundwater elevations were about 4,250 feet above mean sea level (msl) at the San Pedro River at the Mexican border and about 4,000 feet above msl near the USGS stream gage on the San Pedro River near Charleston. A feature to note is the steep water level contours at the base of the Huachuca Mountains.

These water levels represent a part of the aquifer that lies above a shallow buried pediment of the Huachuca Mountains. The aquifer in this part of the sub-basin is much thinner than in the central parts of the Basin, where aquifer thickness may exceed several thousand feet. Another notable feature is the absence of a cone of depression near Sierra Vista.

In 1986, the USGS published a Hydrologic Investigations Atlas that consists of three predevelopment maps as part of the Southwest Alluvial Basins, Regional Aquifer Systems Analysis Project (Freethey and Anderson, 1986). One of the goals of this project was “an overall assessment of hydrologic systems.” These maps include predevelopment water-level contours based on field data collected between the early 1900’s and 1940, historic accounts, numerical models, and recent data where long-term changes in water levels were assumed to be negligible. The water-level contours depicted for the USP Basin are consistent with previous mapping. Attached as Appendix B is the part of the USGS Atlas that covers the USP Basin, including the area north of Fairbank.

Brown and others (1966) published a 1961 water-level elevation map for the southernmost portion of the Basin (see Figure 3-5). As with Freethey (1982) and Corell and others (1996), Brown’s map did not cover the area north of Fairbank. The 1961 map again shows a steeper water-level gradient along the pediment of the Huachucas, but it also shows the beginning of a cone of depression near Sierra Vista, where a decline of up to 50 feet in the groundwater level occurred between 1940 and 1961.

Roeske and Werrell (1973) published a groundwater elevation map for 1968 that covered the entire Sierra Vista sub-basin (see Figure 3-6). This map showed a similar flow pattern to previous water-level maps, with the aquifer being recharged near the mountain fronts and groundwater flowing laterally toward the San Pedro River in the center of the Basin. Roeske and Werrell's map also showed a slightly larger and deeper cone of depression in the Sierra Vista area than Brown's 1961 map. Groundwater levels along the San Pedro River were about the same as shown by Brown. Groundwater levels near Benson were in the range of 3,450 to 3,500 feet above msl.

Konieczki (1980) published a groundwater elevation map for 1978 that also showed the entire Sierra Vista sub-basin (see Figure 3-7). Konieczki's map again showed a steeply-sloping water table along the Huachuca Mountain pediment and a similar cone of depression to that of Brown and others (1966) and Roeske and Werrell (1973). Hydrographs of water-level changes in wells studied by Konieczki (1980) showed annual decline rates of up to 4 feet per year near Sierra Vista and decline rates of 0 to 0.7 feet per year in other parts of the Basin. By 1986, a few parts of the Basin showed water-level rises (Putman and others, 1988). Water levels in wells along the San Pedro River remained largely unchanged.

The Department began collecting extensive groundwater data throughout Arizona in 1980. Quarterly and annual water-level data are collected routinely by the Department in the USP Basin through its index well program. In 1997, the Department published a water-level map for 1990 (Barnes, 1997). In 1989, Burtell published a Master's thesis that covered the Allen Flat sub-basin of the USP Basin. The water-level data from these two reports have been combined as Figure 3-8.

Figure 3-8 shows a cone of depression in the Sierra Vista sub-area and a more disturbed groundwater flow pattern in that area than previously shown. Undisturbed groundwater flowpaths are generally smooth and without sharp bends in elevation contour lines. The 1990 map shows sinuous water-level contour lines in the Sierra Vista area, indicating the influence of pumping wells on the water table.

During the winter of 2001-2002 the Department collected water levels in the entire Basin in support of the present study (Barnes and Putman, 2004). These water levels are shown in Figure 3-9 and show that the general pattern of groundwater flow remained unchanged from 1990. The cone of depression near Sierra Vista is essentially of the same size and location, but has deepened slightly. A very small cone of depression is developing along Greenbush Draw, between Naco and the San Pedro River. This area is used to supply water from wells to Bisbee. Water levels near Pomerene have risen, possibly in response both to less groundwater demand for farming and to recharge from flood flows of the San Pedro River, particularly the October, 2000 flood event. Pool and Coes (1999) published a 1998 water-level elevation map for the southern portion of the Sierra Vista sub-basin. The 1998 map covers the area south of Fairbank and compares closely with the 2001-2002 data collected by the Department.

Figure 3-10 shows the approximate depth to the regional water table, in feet below land surface. Small areas of perched groundwater exist in the Basin. Depth to groundwater will be less in these areas.

<u>Allen Flat Sub-Basin</u>

Depth to groundwater in the Allen Flat sub-basin ranges from less than 10 feet near washes to more than 600 feet near the mountains (Arizona Department of Water Resources, 2002b). Burtell's thesis provides more information on this sub-basin (Burtell, 1989). Figure 3-8 shows water level data reported by Burtell (1989). Water-level data collected by the Department in 2001-2002 were insufficient to construct a detailed groundwater elevation map for the Allen Flat sub-basin. No significant changes in groundwater elevation are expected given that groundwater development within the Allen Flat sub-basin has been negligible.

The majority of the wells in the Allen Flat sub-basin are drilled into the basin-fill. Burtell (1989) reported thick basin-fill units near the edge of the Basin; four wells penetrated 550 to 1,180 feet of alluvium within one mile of exposed bedrock. Well depths throughout the sub-basin range from 20 feet to over 1,300 feet, and well yields range from 1 to 35 gpm (Burtell, 1989; Arizona Department of Water Resources, 2002c).

Figure 3 –4

Upper San Pedro Basin

1940 Groundwater Elevations

(after Corell and others, 1996)

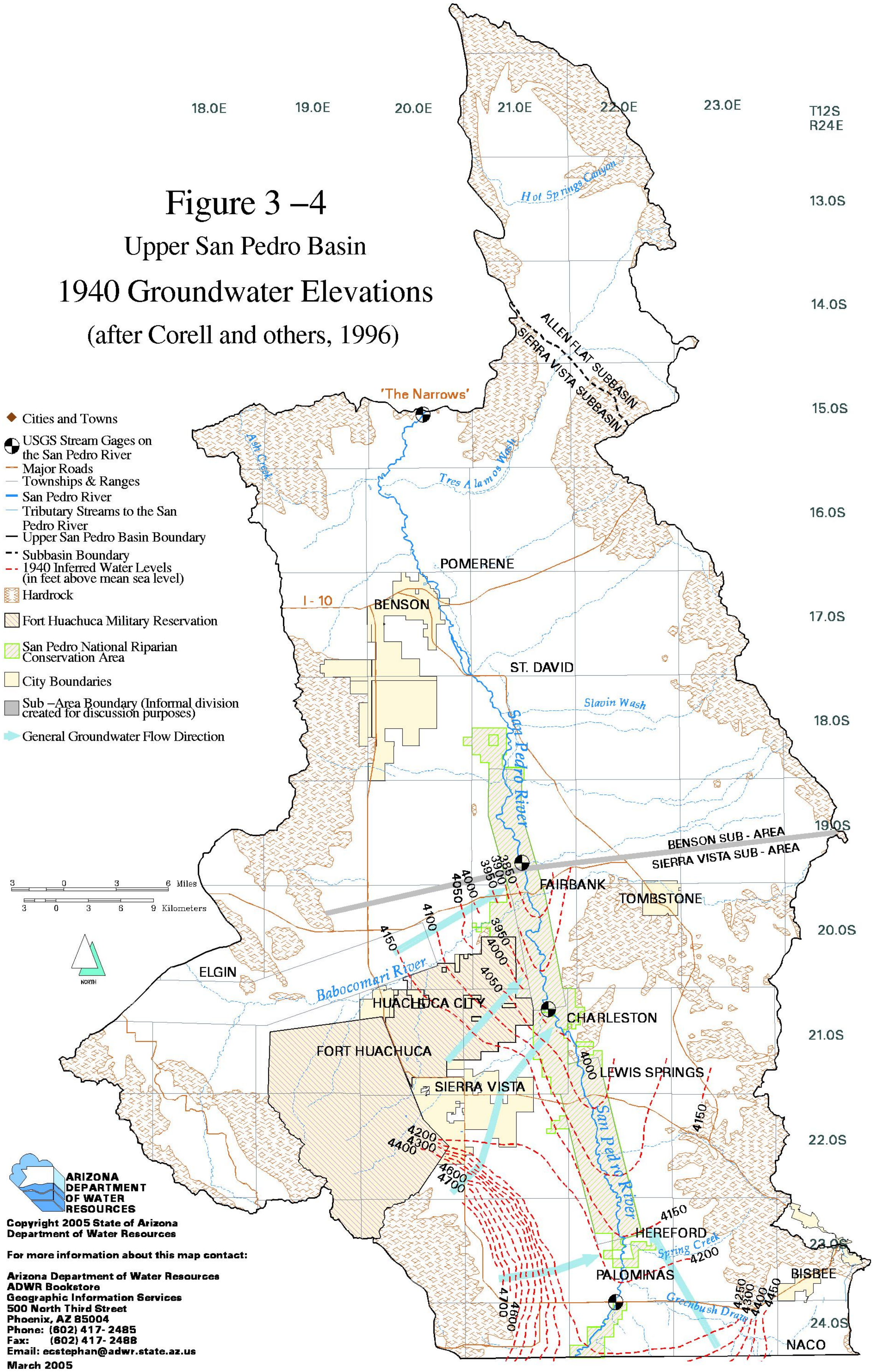


Figure 3 –5

Upper San Pedro Basin

1961 Groundwater Elevations

(after Brown and others, 1966)

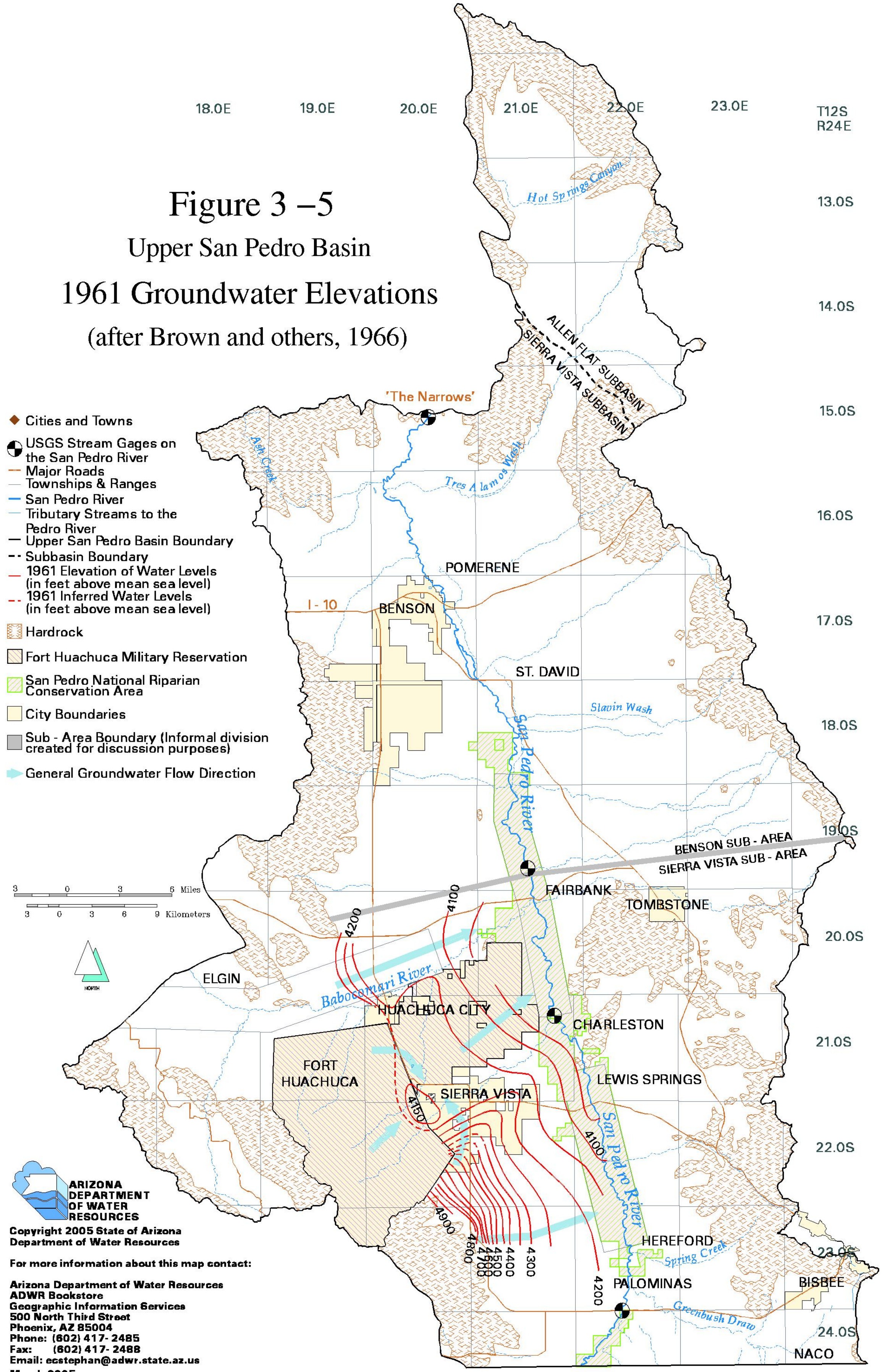


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Figure 3 –6

Upper San Pedro Basin

1968 Groundwater Elevations

(after Roeske and Werrell, 1973)

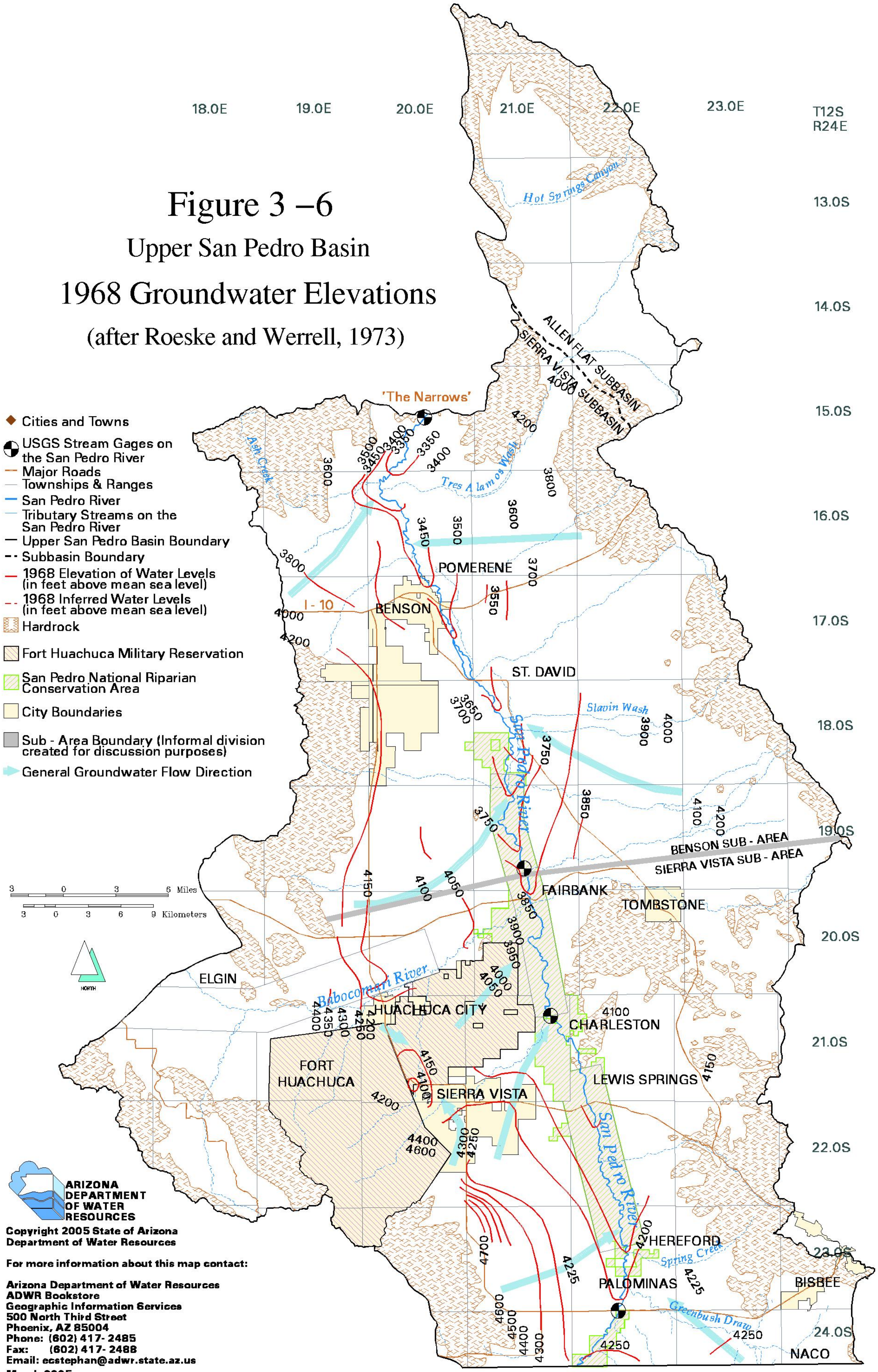

Figure 3 –7

Upper San Pedro Basin

1978 Groundwater Elevations

(after Konieczki, 1980)

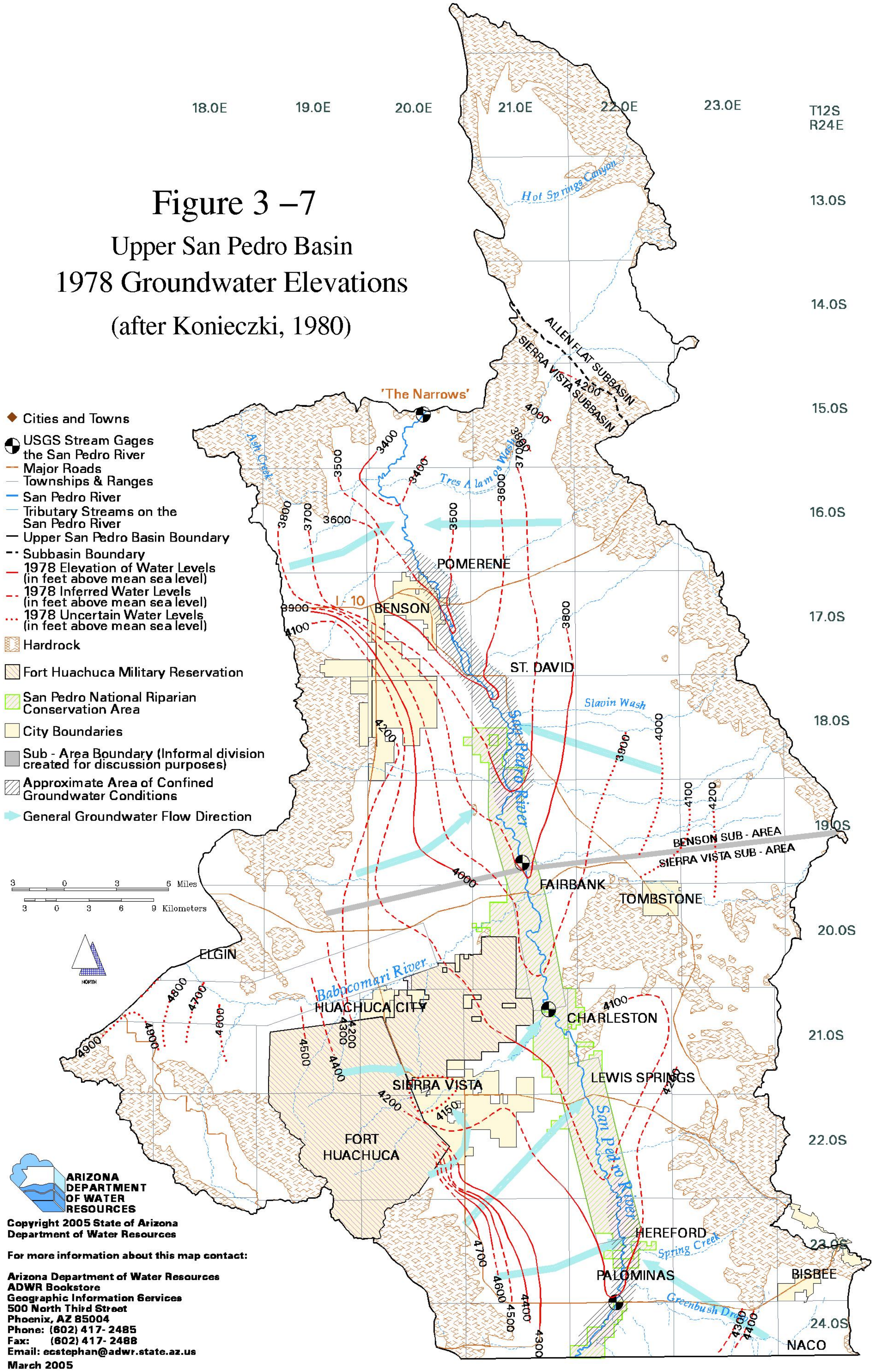

Figure 3 –8

Upper San Pedro Basin

1990 Groundwater Elevations

(after Barnes, 1997 and Burtell, 1989)

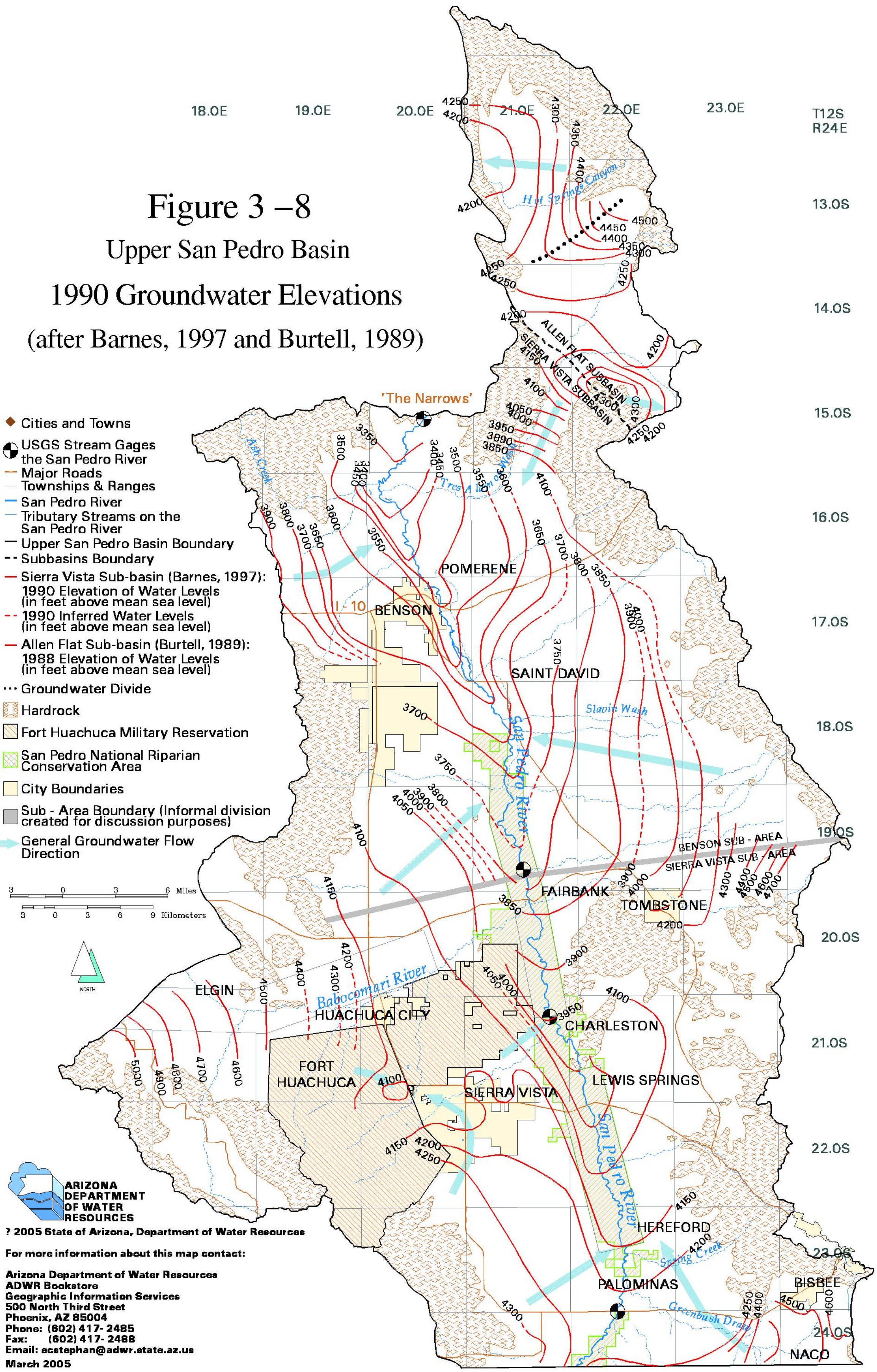

Figure 3 –9

Upper San Pedro Basin

2001 Groundwater Elevations

(after Barnes and Putman, 2004)

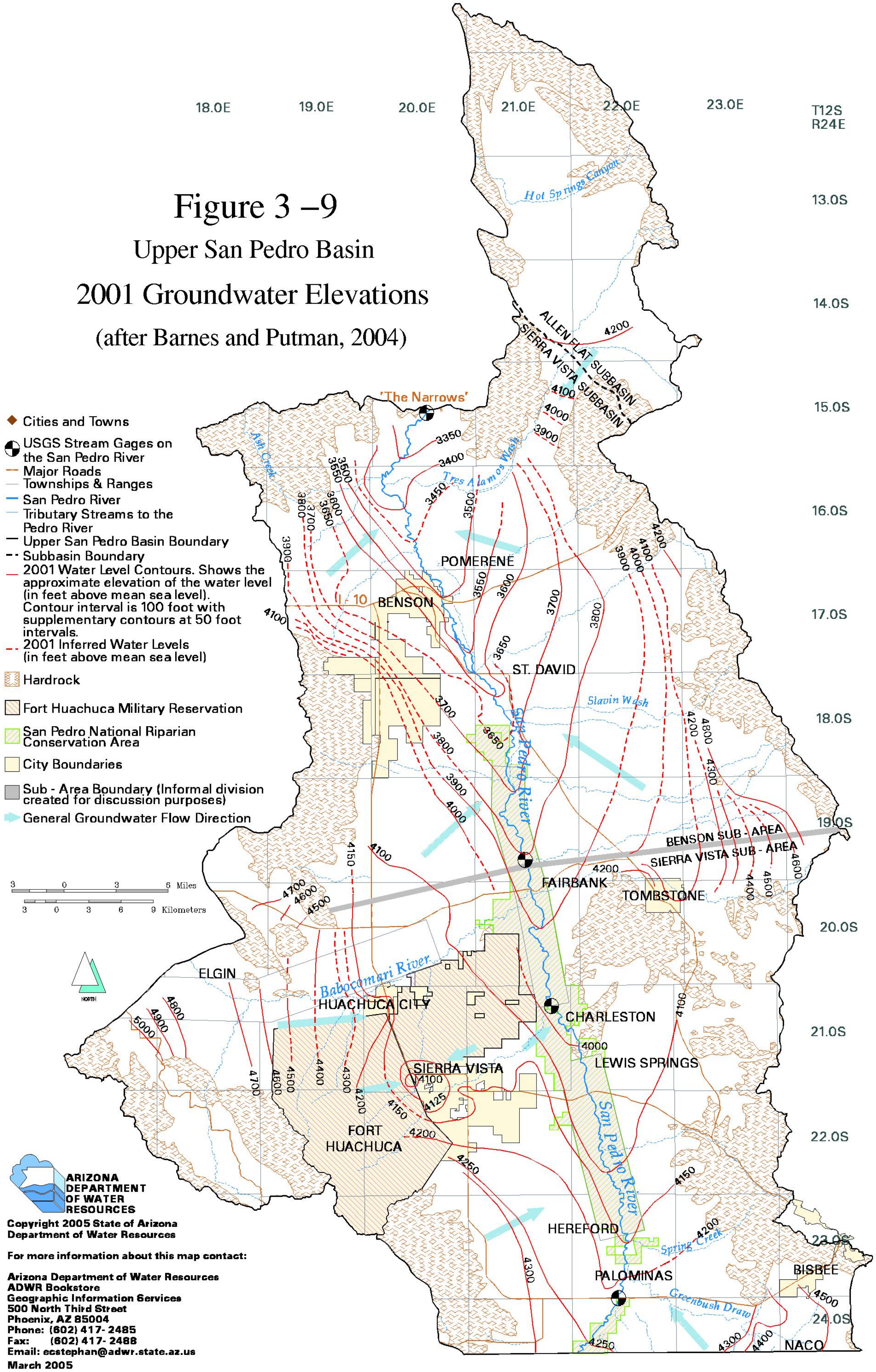

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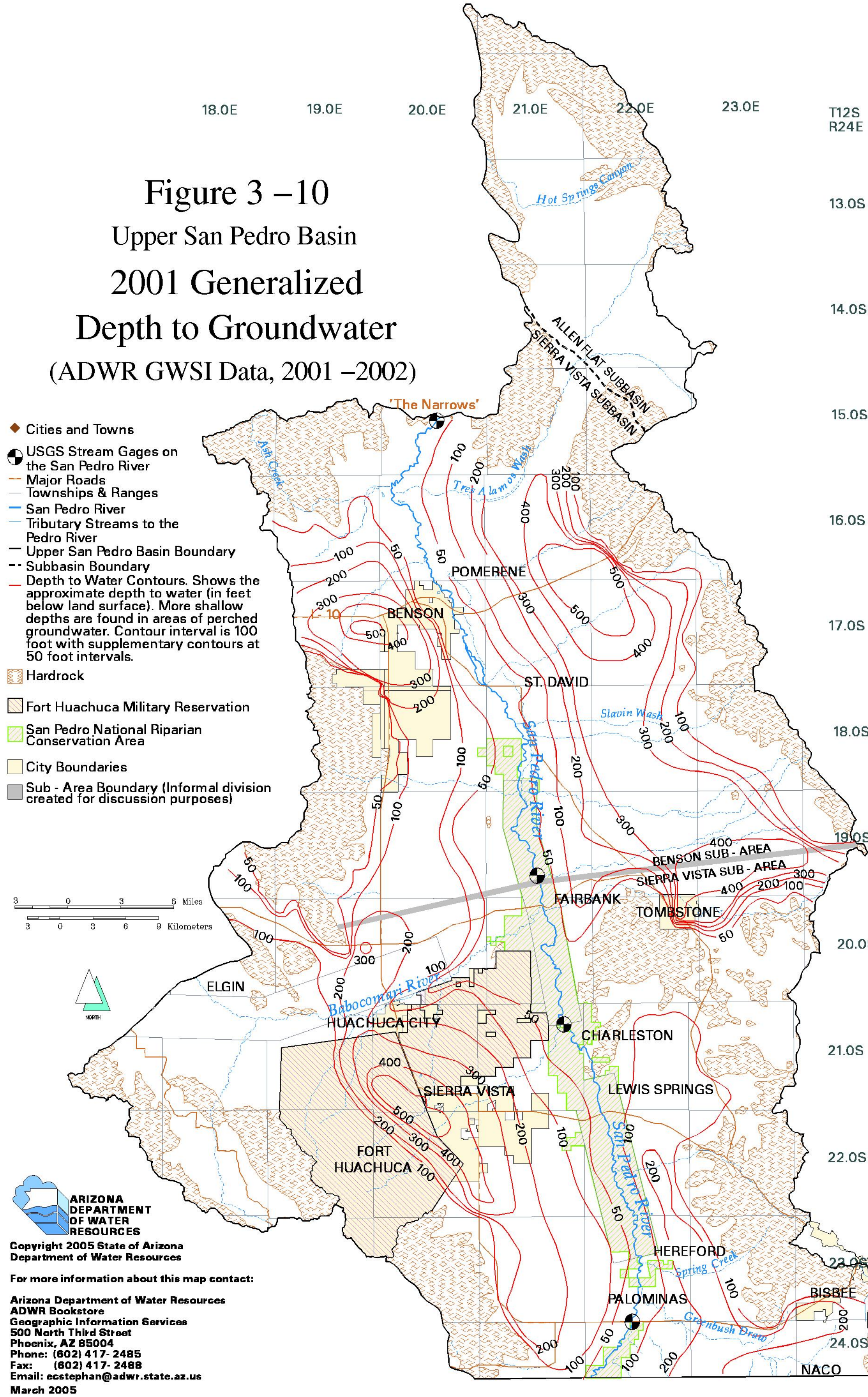
Figure 3 –10
Upper San Pedro Basin
2001 Generalized Depth to Groundwater
(ADWR GWSI Data, 2001 –2002)



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3.1.4 Groundwater Elevation Changes

Basin-wide changes in groundwater levels between 1990 and 2001 are shown in Figure 3-11, along with the location of representative well hydrographs. Figure 3-12 shows the water-level hydrographs for these representative wells (Barnes and Putman, 2004) which are described by general geographic location and cadastral number (see Appendix C for a description of well numbering system). Hydrographs are charts that show water levels or depths to water in a single well over a period of time. The hydrographs are useful in understanding the changes in the aquifer system in localized parts of the Basin.

<u>Sierra Vista Sub-Basin</u>

In the Sierra Vista sub-basin, reasons cited for changes in water levels include pumping, recharge, climatic change (Pool and Coes, 1999) and a regional adjustment associated with downcutting of the San Pedro River that began near Winkelman in 1883 and progressed upstream over the next several decades (Bryan and others, 1934, and Brown and others, 1966). Water-level changes have not been extreme for a large part of the Sierra Vista sub-basin. Most of the hydrographs shown in Figure 3-12 show a slight downward trend over many years. A few hydrographs show steeper downward trends, particularly in the Sierra Vista-Fort Huachuca area where water-level declines have been historically noted. The area between Bisbee and Naco shows changes with the largest declines in the sub-basin from 1990 to 2001 (Barnes and Putman, 2004). Following is a discussion of water-level changes within specific areas of the sub-basin for the 12-year period from 1990 through 2001.

The Narrows – North of Pomerene
Just south of "The Narrows," water-level changes ranged from a rise of 0.1 foot to a decline of 5.3 feet, with an average decline of 1.5 feet. Wells measured along the San Pedro River, north of Pomerene had water-level changes ranging from 0 to a maximum rise of 11.1 feet, with an average rise of 4.7 feet (Barnes and Putman, 2004). Most wells in this area are shallow.

Pomerene - Benson
Moderate water-level declines were recorded in both the shallow aquifer and deeper regional (artesian) aquifer in the Pomerene–Benson area. Water-level changes in the shallow aquifer ranged from a rise of 0.5 feet to a decline of 10.2 feet, with most declines in the 1.0 to 5.0 foot range. Changes in deep wells ranged from a rise of 0.3 feet to a decline of 18.9 feet, with most declines in the 4.0 to 9.0 foot range (Barnes and Putman, 2004). In the Benson area, along Interstate 10, water-level declines ranged from 5.0 to 7.0 feet, with a maximum decline of 11.8 feet. A cone of depression appears to be forming in this area in the vicinity of a municipal wellfield. Planned development near Benson (Whetstone Ranch) will probably be served water by a wellfield near Benson, and a cone of depression southwest of Benson may develop as a result.

St. David

In the St. David area, a large number of wells were completed in the shallow aquifer and a large number were completed in the deeper, regional (artesian) aquifer. Water-level changes ranged from a rise of 12.9 feet to a decline of 11.1 feet. In the shallow aquifer south of St. David, recorded declines in water-levels were about 1 foot per year. Wells completed in the regional aquifer showed the least amount of change; several wells reflected a rise in water level of up to 5 feet (Barnes and Putman, 2004).

Sierra Vista-Huachuca City-Nicksville

Water-level declines in the Sierra Vista area have been historically noted and have continued to decline from 1990 to 2001. Declines in water-levels in and around Sierra Vista range from 1.2 feet to 14.8 feet in a public supply well. This public supply well has a recorded average water-level decline of 1.4 feet per year for the period 1990-2001. Most wells within the cone of depression have water-level declines of less than 1 foot per year. The depression has been generally expanding in an east-southeasterly direction from the deepest part of the cone. Hydrographs K, L, M and O show the steady decline in water levels within the cone of depression (Barnes and Putman, 2004).

North of Sierra Vista, water-level declines became less pronounced for the period 1990-2001 than in prior years. Between Sierra Vista and Huachuca City, water-level declines between 5.0 feet and 7.0 feet were recorded; north of Huachuca City, recorded declines were between 1.0 foot and 5.0 feet. A public supply well in this area had a water-level decline of 13.4 feet (1.22 ft/yr) since 1990 (Barnes and Putman, 2004).

South of Sierra Vista, near Nicksville, a wide range of declines and rises have occurred since 1990. Water-level declines ranging from 26.4 to 35.4 feet have been recorded. Closer to the foothills of the Huachuca Mountains, water levels become more varied ranging from a decline of 8.7 feet to a rise of 16.6 feet; these extreme fluctuations are shown on Figure 3-11. Many of the wells near the mountains are completed on the pediment in fractured hardrock and are more susceptible to rainfall or drought conditions than wells completed in the regional aquifer (Barnes and Putman, 2004).

Tombstone

Water-level declines in the Tombstone area range from less than 1.0 foot to 23.1 feet. Many of the declines are in shallow, windmill wells located near washes. Three deep (600-890 feet) public supply wells had declines ranging from 3.3 feet to 23.1 feet (Barnes and Putman, 2004).

Naco-Bisbee

The sharpest water-level declines in the USP Basin have occurred in the Naco area, with declines ranging from 9.8 feet to 32.1 feet. A cone of depression appears to be forming southwest of Bisbee along Greenbush Draw close to a municipal wellfield. Prior to 1997, discharge of mine water to evaporation ponds in the vicinity of Warren Ranch near Naco probably recharged the aquifer in the area now experiencing sharp water-level declines (see section 3.1.6). Toward the San Pedro River to the west, water levels ranged from a rise of 1.0 foot to a decline of 4.1 feet (Barnes and Putman, 2004).

International Boundary – Hereford
South of Hereford to the United States-Mexico International Boundary, water-level changes have ranged from a rise of 7.0 feet to a decline of 4.9 feet, with most wells showing changes of +/- 3.0 feet.

Allen Flat Sub-Basin

Very little change in water levels has occurred in the Allen flat sub-basin. Hydrographs were constructed from two wells located near Tres Alamos Wash in the Allen Flat sub-basin and are shown as A and B on Figure 3-11. Hydrograph A for well (D-14-21) 11BBC shows a slight water-level rise of 0.1 feet per year from 1968 through 2001. Hydrograph B for well (D-14-22) 34BDC shows a water-level decline of 0.6 feet per year from 1968 through 2001 (Figure 3-12). Data were not available to construct hydrographs for other wells in the sub-basin.

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Figure 3 –11

Upper San Pedro Basin

Well Hydrograph Locations and Groundwater-Level Changes 1990 –2001 (ADWR GWSI Data, 2002)

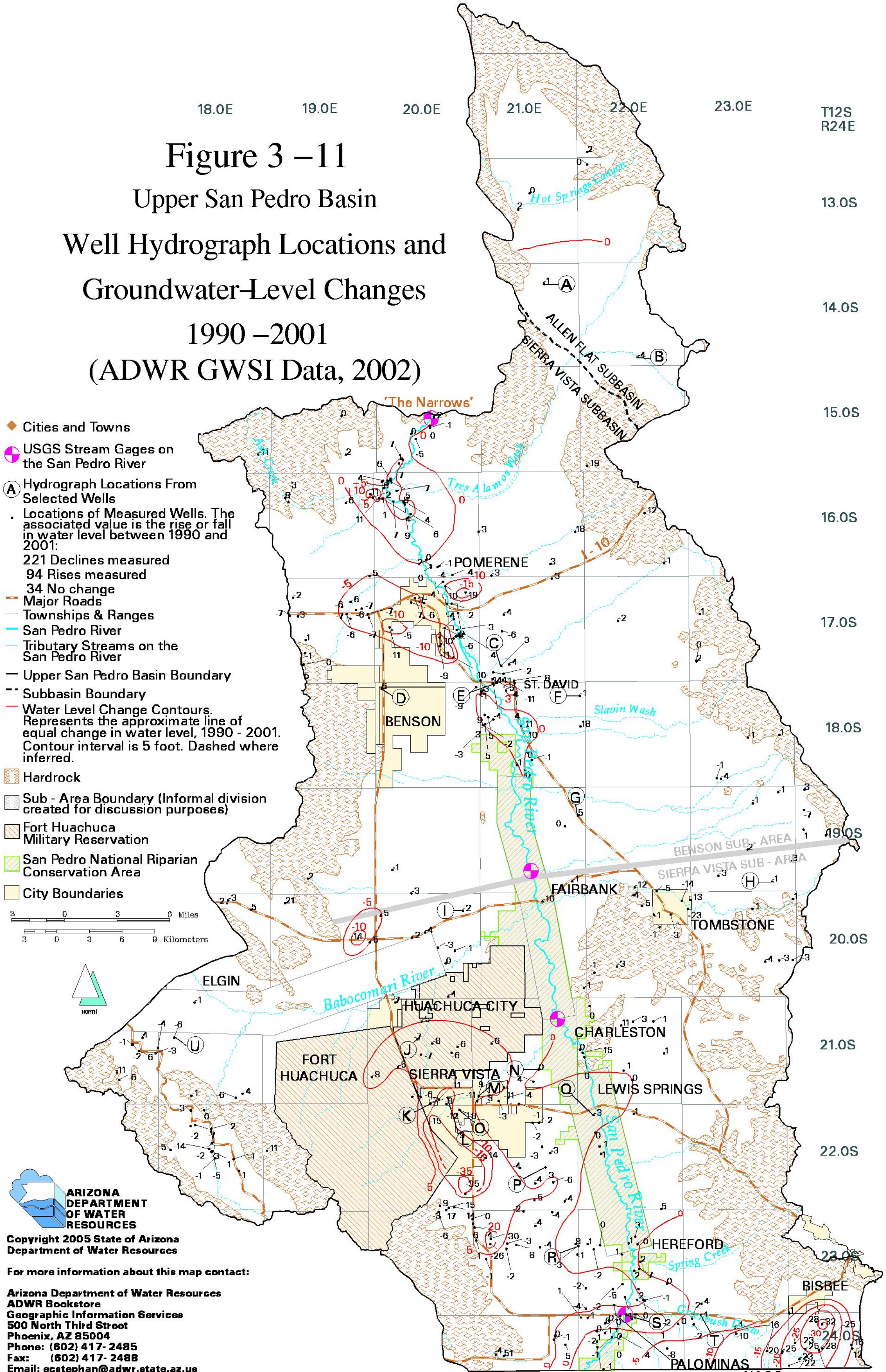
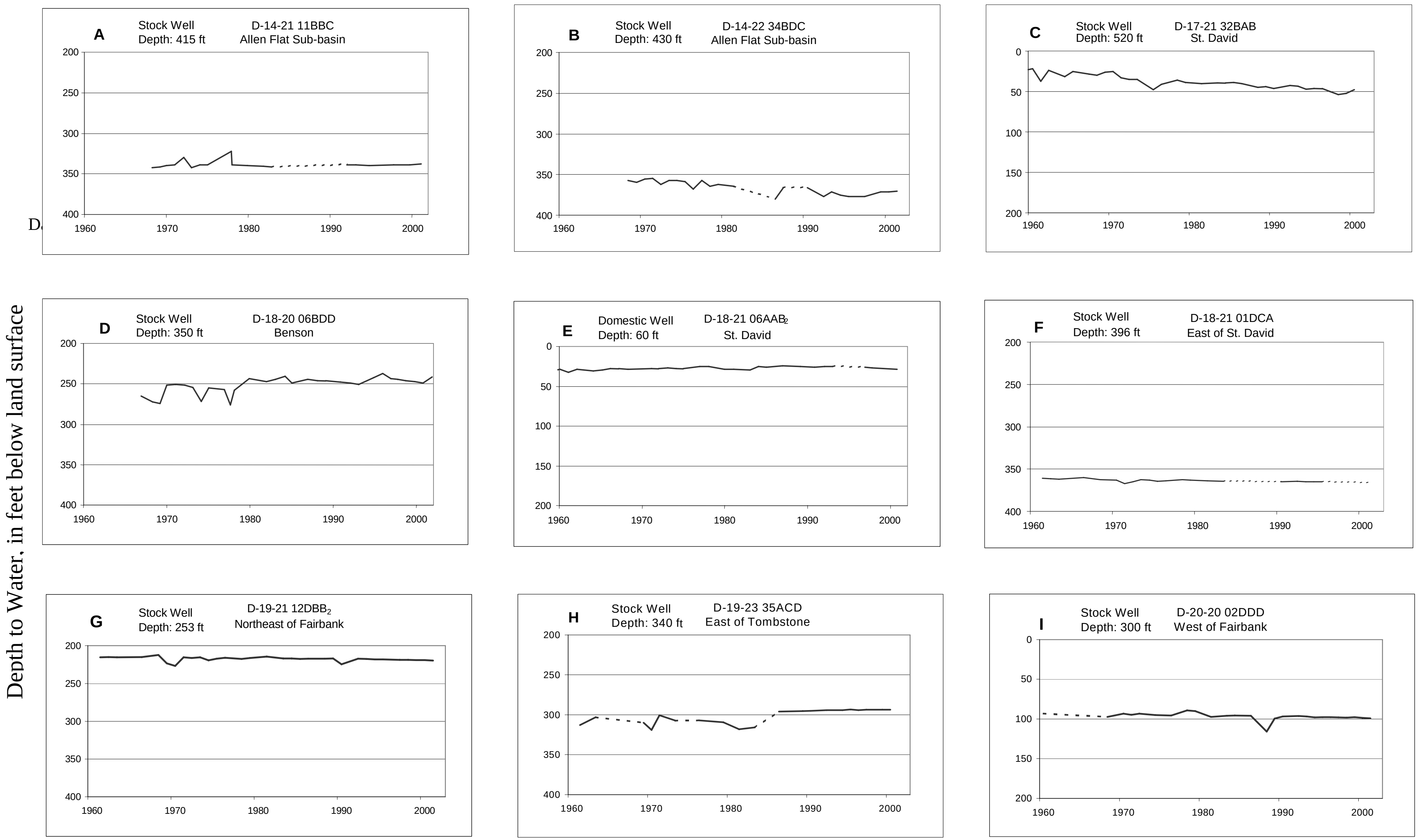
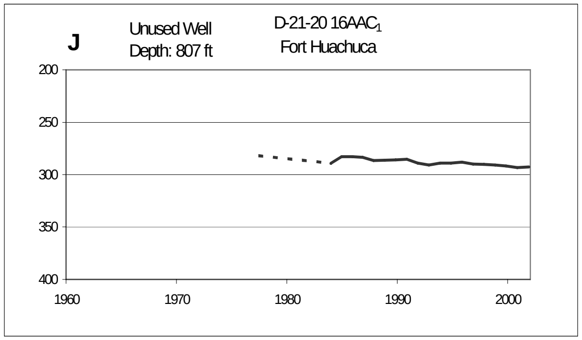
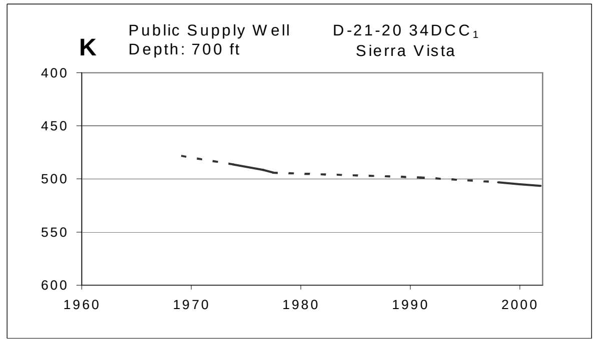


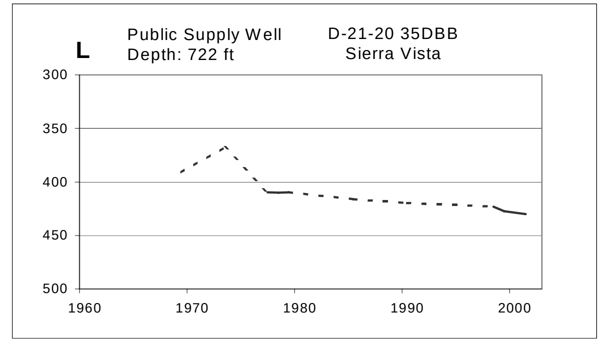
Figure 3-12. Hydrographs of Water Levels in Selected Wells.

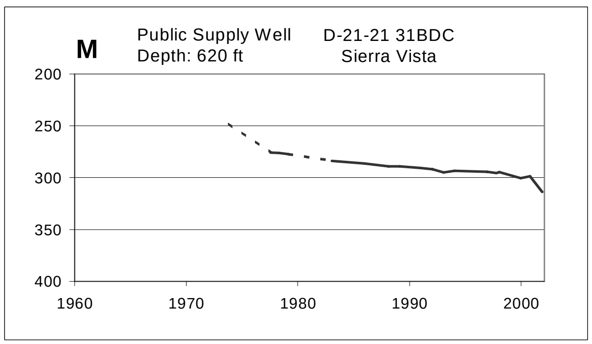


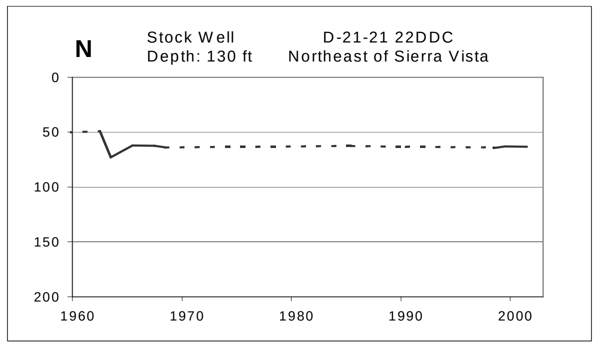
Depth to Water, in feet below land surface

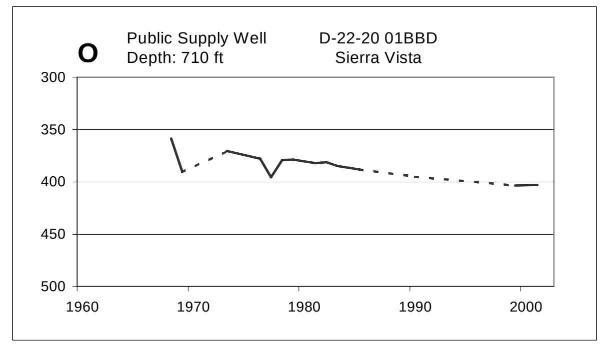


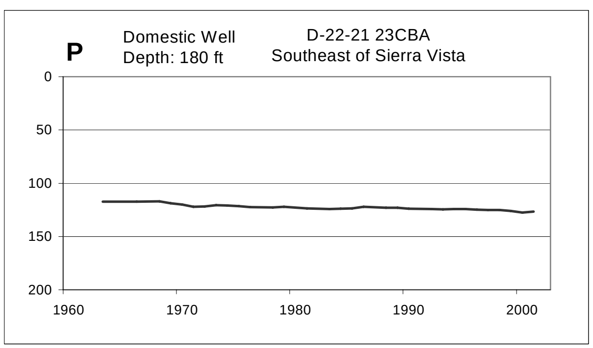


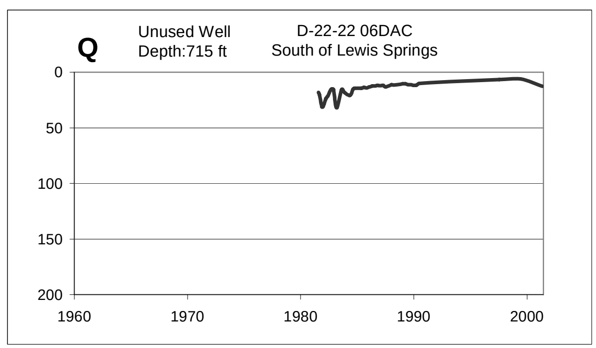


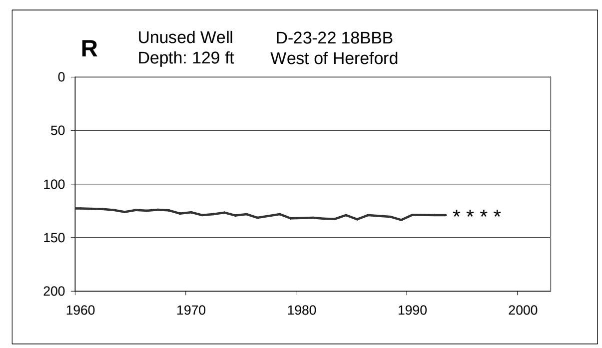


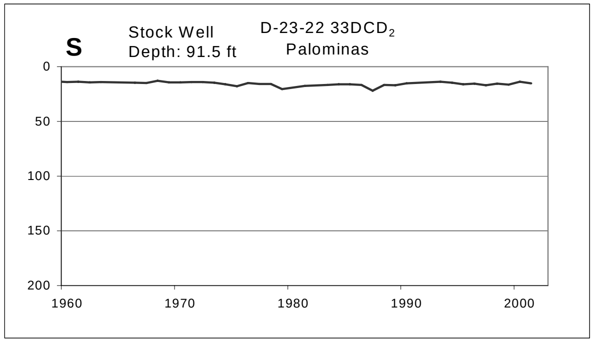


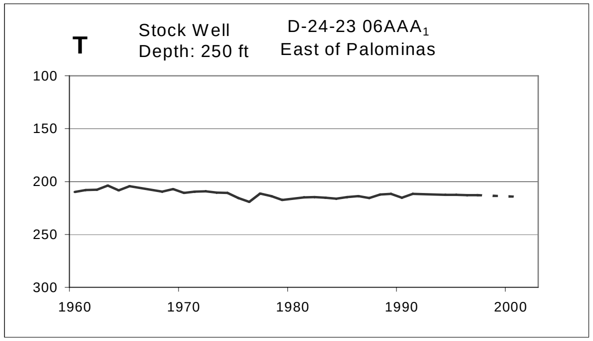


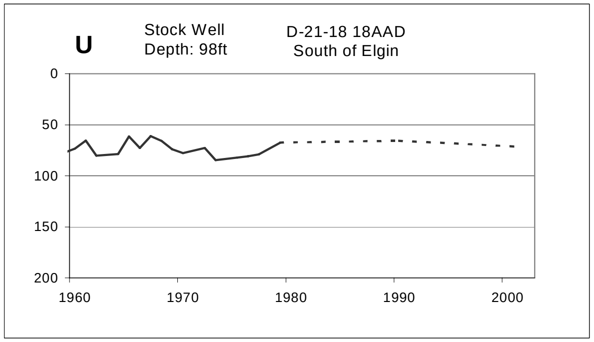












Note: Asterisk indicates a dry well.

Dashed line indicates an inferred water-level.

3.1.5 Groundwater in Storage

An estimate of the amount of groundwater stored in the regional and floodplain aquifers within the Sierra Vista sub-basin was made for this study by the Department. Data used were water levels collected by the Department in winter, 2001-2002 (Arizona Department of Water Resources, 2002b), depth to Pantano (?) Formation and depth to bedrock maps from Gettings and Houser (2000) and a depth to bedrock map from Oppenheimer and Sumner (1980). Estimates of aquifer specific yield were from Corell and others (1996) and from literature surveys. Groundwater in storage was not estimated for the Allen Flat sub-basin given the paucity of data for this area.

In the upper and lower basin-fill, the Department estimated that about 15.6 million acre-feet of groundwater remains in storage within the Sierra Vista sub-basin. In the upper and lower basin-fill, a specific yield of 8% was used for this estimate (Corell and others, 1996), and the volume of basin-fill considered was the portion between the water table and either hydrologic bedrock or the Pantano (?) Formation, or 1,200 feet below land surface if the basin-fill extended deeper than this distance. Figure 3-2 (Depth to Top of Pantano (?) Fm) was used to estimate basin-fill thickness. The Department does not consider water at depths below 1,200 feet to be economically recoverable, and uses this depth as its cut-off for useful aquifer storage depth. This storage estimate is less than previous estimates because new data from Gettings and Houser (2000) show that the thickness of alluvium is substantially less in some areas than previously thought by other researchers. The Getting and Houser study estimated the thickness of basin-fill and depth to bedrock using a sophisticated procedure involving interpolation of a residual gravity anomaly grid and stratigraphic data.

The Pantano (?) Formation is a conglomerate that underlies the basin-fill, and most of its water is probably yielded to wells through fractures in the conglomerate (Pool and Coes, 1999). Gettings and Houser (2000) mapped the depth to the top and bottom of a sedimentary unit underlying the basin-fill in most of the Sierra Vista sub-basin. South of Huachuca City, Gettings and Houser (2000) identified this unit as the Pantano (?) Formation. North of Huachuca City, Gettings and Houser did not confirm the identity of the underlying unit. The volume of groundwater storage in the Pantano (?) Formation between the basin-fill and a depth of 1,200 feet below land surface was estimated at 3.8 million acre-feet using a specific yield of 3% and depth to bedrock information from Gettings and Houser (2000). This specific yield value of 3% was based on a literature review of values for fractured rocks (Davis and DeWiest, 1966; Fetter, 1994; Walton, 1970). Corell and others (1996) modeled the Pantano (?) using a specific yield of 8%, which allows an estimate of water in storage of about 10.1 million acre-feet. The Pantano (?) Formation is largely unexplored in the Basin and the estimate of water in storage is subject to re-evaluation when more data are available.

The floodplain aquifer of the USP Basin is a shallow and narrow shoestring aquifer, which is quite productive but limited in the amount of groundwater it can store. Groundwater in storage was estimated at 421,000 acre-feet (Putman and others, 1988).

Total groundwater storage in the Sierra Vista sub-basin was estimated between 19.8 million and 26.1 million acre-feet. This range is considerably less than the 41 million acre-feet of storage estimated in ADWR's HSR (1991a) and the estimate of 48 million acre-feet cited by Putman and others (1988). The difference comes from re-definition of the depth to bedrock by Gettings and Houser (2000), and from use of lower specific yield estimates. The estimate of 48 million acre-feet cited in Putman and others (1988), was taken from a 1975 report by the Arizona Water Commission (1975), which in turn cited unpublished data from the USGS. Although the groundwater storage estimate is considerably less than previous estimates, there are considerable groundwater resources available.

3.1.6 Groundwater Budget

A groundwater budget is an accounting of inflows to an aquifer and outflows from an aquifer. The difference between the two results is a change in groundwater in storage. The difference is not constant from year to year, but over a long period of time can indicate if a groundwater system is in an overdraft situation. The Department developed a groundwater budget for the USP Basin by examining inflows and outflows in the groundwater system in the Sierra Vista sub-area and the Benson sub-area. For the purposes of this report, the Department divided the USP Basin into the "Sierra Vista sub-area" and the "Benson sub-area." These informal divisions were created by the Department to allow water use by sectors (primarily municipal and agricultural) to be discussed by geographic location. The Sierra Vista sub-area includes the portion of the USP Basin from the U.S. Mexico border to Fairbank. The Benson sub-area extends from Fairbank to "The Narrows," including the Allen Flat sub-basin (see Figure 3-2).

Inflows

Major inflows into the groundwater system come from recharge of water along the fronts of the Huachuca, Mule, Whetstone, Rincon and Dragoon Mountains (including ephemeral channel recharge), from groundwater flowing across the Mexican Border, and from recharge of flood flows of the streams in the Basin. Secondary sources are recharge of water from recharge projects, septic tanks, and golf courses.

<u>Sierra Vista Sub-Area</u>

Mountain front recharge estimates are available from Corell and others (1996), ADWR's HSR (1991a), Jahnke (1994), Anderson and Freethey (1994), and Goode and Maddock (2000). Estimates for the Sierra Vista sub-area of the Sierra Vista sub-basin are believed to be more accurate than for the Benson sub-area because of the many studies that have taken place in the southern part of the USP Basin. Estimates for the Benson sub-area are more generalized and less precise.

Corell and others (1996) estimated that a total of 19,000 acre-feet per year recharges the groundwater system of the Sierra Vista sub-area. This included mountain front recharge and ephemeral stream channel recharge, including 1,000 acre-feet of recharge along Greenbush Draw (Corell and others, 1996), and about 3,000 acre-feet per year of groundwater flux from Sonora to Arizona. This mountain front recharge and ephemeral stream recharge estimate was derived from baseflow records of the San Pedro River at the Palominas, Charleston, and Tombstone stream gaging stations (USGS Water Resources Data for Arizona, various years). It was assumed for this estimate that during the earliest period of record, before the Basin was heavily pumped, that the water discharging from the aquifer to sustain baseflow of the river was equal to the water entering the aquifer from various recharge sources. The earliest period of baseflow records used was from 1935-1941. A full explanation is provided in Corell and others (1996).

The cross-border flux estimate was obtained from a flow net analysis (Putman and others, 1988). The recharge along Greenbush Draw was assumed by Corell and others (1996) to offset decades of pumping by the Arizona Water Company in that area. The Greenbush Draw area showed little or no groundwater decline until about 1990. Between 1990 and 2002 water levels had declined by 20 to 30 feet in some areas. Recharge in Greenbush Draw was assumed to be natural by Corell and others (1996), but recent discussions with Cochise County staff and Phelps Dodge staff revealed that the recharge probably came from discharge of mine water to evaporation ponds in the vicinity of Warren Ranch, near Naco, Arizona. This practice ended in 1997 (SAVCI Engineering Technology, 1998). The Greenbush Draw recharge estimate of 1,000 acre-feet was therefore removed from the prior estimate of 19,000 acre-feet used by Corell and others (1996). The revised estimate of 18,000 acre-feet was chosen for the water budget. Recharge from flood flows of the San Pedro River is felt to be minimal in the Sierra Vista sub-area because the water levels in the floodplain alluvium are maintained at shallow levels, making little storage space available for long-term aquifer storage.

Recharge from various other sources such as recharge projects and septic tanks was estimated using information provided by the City of Sierra Vista, Fort Huachuca, and other water providers, as well as from water use estimates from Department staff as discussed in Chapter 4. Recharge Facility Annual Reports filed with the Department by the City of Sierra Vista and a report by Fort Huachuca (U.S. Army, 2002) show that about 1,500 acre-feet of effluent were recharged in 2002. Municipal and industrial incidental recharge was estimated at about 2,000 acre-feet per year. Total recharge to the groundwater system in the Sierra Vista sub-area is estimated at about 21,500 acre-feet per year.

<u>Benson Sub-Area</u>

Estimates of recharge in the Benson sub-area are based on fewer studies. The Department's HSR (1991) estimated mountain front recharge at about 11,800 acre-feet per year. Jahnke (1994) estimated mountain front recharge at about 10,700 acre-feet per year. Anderson and Freethey (1994) estimated mountain front recharge at 9,400 acre-feet per year. The budget uses 10,600 acre-feet per year, which is an average of the three estimates. Recharge from various other sources such as recharge projects and septic tanks was estimated using information provided by water providers, as well as from water use estimates from Department staff, which are discussed in detail in Chapter 4. Municipal and industrial incidental recharge was estimated at about 600 acre-feet per year.

Recharge from the San Pedro River constitutes a major source of recharge in the Benson sub-area but is poorly quantified due to lack of data. River recharge may occur during periods of baseflow and during flood events. A comparison of average monthly river flows at the USGS stream gage, "San Pedro River near Tombstone" (#09471550) and the USGS stream gage, "San Pedro River near Benson" (#09471800) at an area known as "The Narrows," was used to estimate transmission losses of river flows through the Benson sub-area. (Arizona Department of Water Resources, Hydrology Division, unpublished analysis, May 2004; U.S. Geological Survey, 2004b). The only overlapping period for the two gages was 1967 to 1976, or 9 years of common record. This comparative study showed that average monthly inflows up to 25 cubic feet per second (cfs) almost always were completely lost to infiltration, evaporation, diversion, or riparian use within the Benson sub-area, and outflow at "The Narrows" was usually zero for these inflow rates. The transmission losses for monthly average flows under 25 cfs amounted to a total of about 48,000 acre-feet over 9 years, or an average of 5,300 acre-feet per year. As stated above, not all of the infiltrated water recharged the aquifer, since there were channel evaporative losses, diversions and use by riparian vegetation.

Average monthly inflows above 25 cfs displayed a mixed pattern of losses or gains in flow within the Benson sub-area (Arizona Department of Water Resources, Hydrology Division, unpublished analysis, May 2004). Probable reasons for this were that the larger inflows represented larger, regional storm events, and considerable runoff was generated within both the Benson and Sierra Vista sub-areas. When precipitation was more intense within the Benson sub-area, the sub-area outflows exceeded the inflows. Between 1967 and 1976 , there were 31 months when monthly average inflows exceeded 25 cfs. In 20 of the 31 months there were transmission losses within the Benson sub-area. In the other 11 months the sub-area outflows at "The Narrows" exceeded the inflows at the Tombstone gage. The transmission losses for the 20 months identified above amount to a total of 35,000 acre-feet over 9 years, or an average annual transmission loss of about 3,900 acre-feet. As stated above, not all of the infiltrated water recharged the aquifer, since there were channel evaporative losses, use by riparian vegetation, possible diversions, and perhaps bank storage discharge to the stream that later left the USP Basin.

Average river infiltration for the period 1967-76 may therefore have been as high as 9,200 acre-feet from a combination of low flows (5,300 acre-feet) and flood flows (3,900 acre-feet), although this seems unlikely because of the riparian uses, evaporation and diversions noted above. A study of winter baseflows into the Benson sub-area during 1997-2003 indicates that about 3,100 acre-feet of stream flow infiltrated into the streambed during that season. Because water use is minimal during the winter, this infiltrated baseflow recharged the groundwater system. Using an average between the high estimate of 9,200 acre-feet and the low value of 3,100 acre-feet gives an estimate of 6,150 acre-feet of river recharge. The estimate of 6,150 acre-feet of recharge is comprised of 3,100 acre-feet of winter baseflow out of the Sierra Vista sub-area and a balance of 3,050 acre-feet of recharge from higher flow events. This estimate should be regarded with caution because of the limited data available and because the time period of the data may not represent modern conditions.

An additional 440 acre-feet of underflow in the floodplain alluvium enters the Benson sub-area at the Tombstone gage. This quantity was determined using model results from Corell and others (1996). Total inflows to the Benson sub-area groundwater system are estimated at about 17,800 acre-feet per year.

Outflows

Following is a summary of the water use by the sectors discussed in detail in Chapter 4. This section focuses on current water demand, while Chapter 4 includes a discussion of historic and projected water demand.

Water used in the USP Basin is mostly pumped from underlying aquifers. An estimated 27,720 acre-feet per year was pumped in the Basin in 2002, mostly for municipal and military uses near Sierra Vista and Fort Huachuca and for agricultural purposes near Benson and St. David. Artificial recharge is the volume associated with the Fort Hauchuca and Sierra Vista effluent recharge facilities. Incidental recharge is from septic tanks, golf course irrigation and effluent discharge.

Minor amounts of groundwater are used for stock and other industrial uses at this time. An additional 17,350 acre-feet per year of groundwater is used by riparian vegetation along the San Pedro and Babocomari Rivers (Cliff Dahm, University of New Mexico, personal commun., May, 2004; Scott and others, 2004, in preparation; Dahm and others, 2002; Chehbouni and others, 2000; Snyder and Williams, 2000). Additional riparian demand is supplied directly from precipitation and bank storage after flood events.

The amount of groundwater pumped from the Allen Flat sub-basin is used primarily for stock and domestic supplies. Burtell (1989) includes a detailed list of water use for each well inventoried. Additionally, a recent review of registered wells and associated water uses indicate the following: stock use – 60%, stock and domestic use – 18%, domestic use – 12%, and mineral exploration – 10% (Arizona Department of Water Resources, 2002c).

Agriculture

The agricultural demand was estimated from the acres observed as being irrigated, multiplied by the consumptive use of the crops grown. It does not reflect the amount of water diverted, pumped or applied to irrigated acres. Consumptive use is the volume of water used by plants for growth and transpiration. Data on water diverted, pumped or applied were generally not available.

Sierra Vista Sub-Area

In 2003, ADWR staff visited potentially irrigated lands in the Sierra Vista sub-area to field verify their status. The Department estimated that 800 acres were being irrigated based upon a combination of field investigation, San Pedro HSR information, LANDSAT imagery and aerial photographs. There was no evidence of surface water diversions in the 2003 field surveys, although a limited amount of surface water may be diverted at some locations. The watershed file reports from the San Pedro HSR indicate that both surface water and groundwater could have been used on some parcels at that time (ADWR, 1991b). It is estimated that annual consumptive agricultural groundwater use in the Sierra Vista sub-area was 2,500 acre-feet in 2002.

Benson Sub-Area

San Pedro River water is directly diverted for agricultural use in the Benson sub-area by the St. David Ditch and the Pomerene Canal. There are few diversion records on the canal, but those that exist are presented in Table 3-1 of this report. These canals diverted an average of about 6,000 acre-feet per year between 1968 and 1972 (U.S. Geological Survey, 1968-72). At times, the water in the St. David Ditch and Pomerene Canals is heavily supplemented by water from wells (Putman and others, 1988). Putman and others (1988) noted that only 278 acres served by the St. David Ditch were irrigated entirely with surface water. The diversion structures for both canals were damaged by flood events and were not in use when the Department did a field survey of that area in May 2002.

Hourly pumpage and diversion records for the St. David Ditch supplied by the St. David Irrigation District to the Department indicated that about 3,500 acre-feet were pumped and diverted during 2001 for distribution by the ditch. No recent records were available for the Pomerene Canal. Total diversions by both canals were estimated at about 3,350 acre-feet for the period around 2002, using data from the ADWR HSR (1991a) for Pomerene canal and recent data from the St. David Ditch Association. Data in the HSR show that 72%-76% of the diverted water to the Pomerene Canal and St. David Ditch served to satisfy consumptive crop use, thus about 2,300 acre-feet of surface water was assumed to satisfy crop consumptive use in the water budget for the Benson sub-area. The rest of the diverted water was returned to the River, lost to canal seepage, or lost to deep percolation beneath the fields. It should be noted that the precision of these estimates is, at best, to the nearest hundred acre-feet.

Table 3-1. USGS Stream Gaging Stations Located Directly Downstream of the Pomerene Canal and the St. David Ditch Diversion Works.

Station		Total Diversions in Acre-feet[1]					
Station Number	Station Name	1968	1969	1970	1971	1972	Average
09471560	St. David Ditch near St. David, AZ	4,600	4,020	4,140	4,600	5,680[2]	4,608
09471590	Pomerene Canal near St. David, AZ	1,740	1,450	710	1,070	1,950	1,384

(Putman and others, 1988)

[1]Data from published USGS flow records (U.S. Geological Survey, 1968-72); gages began operating in June, 1967

[2]Release of diverted water back to river before usage had been measured as 5.46 cfs in January, 1972 and estimated as 0.1 cfs in March, 1972 (U.S. Geological Survey, 1968-72).

Farming use in the St. David-Benson-Pomerene area was estimated at about 7,300 acre-feet in 2002, based on a survey of agricultural activity conducted by the Department in May 2002. This survey found about 2,150 acres being actively irrigated, mostly as pasture. The farming practice in the Basin has been generally to deficit irrigate (Heindl, 1952; Arizona Department of Water Resources, HSR, 1991a; Corell and others, 1996; Paul Kartchner, personal commun., February, 2002), and a consumptive use factor of 3.4 acre-feet per acre is regarded by ADWR as generally being the upper limit on agricultural use in the Basin (Arizona Department of Water Resources, 1991a). Water applied in excess of the consumptive use is assumed to recharge the shallow aquifer underlying the fields along the river. Appendix D gives more detail on the Department's May, 2002 survey. Of the 7,300 acre-feet of agricultural consumptive use, an estimated 2,300 acre-feet were supplied by surface water diversions as discussed above, and 5,000 acre-feet were supplied by groundwater pumping.

Municipal

Municipal demand includes water served by public and private water systems, water use at Fort Huachuca and domestic (exempt) well demand. Included in this demand is residential, non-residential, golf course and industrial use served by a water system. Municipal water use information came from several sources. A primary source was the Arizona Corporation Commission (ACC), which regulates private water company rates and requires annual reporting of the volume of water pumped and the volume of water sold to customers. Other information on municipal water use came from direct communication with water providers and from estimates of water use for domestic wells. Almost all the water supply for municipal use is groundwater. Effluent is served by municipal water providers for turf irrigation in both sub-areas and a small volume of surface water is used in the Sierra Vista sub-area.

Sierra Vista Sub-Area

Approximately 80% of the Basin municipal demand occurs in the Sierra Vista sub-area. In 2002, water system demand was about 9,300 acre-feet, Fort Huachuca demand was about 1,900 acre-feet (U.S. Army, 2002) and exempt well use about 3,900 acre-feet.

Ninety-six percent of the municipal water demand in the Sierra Vista sub-area (14,500 acre-feet) is met by pumping groundwater. After use, approximately 3,500 acre-feet of water is returned to the aquifer as incidental or artificial recharge. In 2002, about 420 acre-feet of effluent was directly used for turf irrigation at Fort Huachuca. Surface water is diverted from springs in Miller Canyon in the Huachuca Mountains for use in Tombstone via the Tombstone pipeline. This surface water use is estimated at 156 acre-feet per year as reported in the 1988 Putman and others report.

Benson Sub-Area

In 2002, total water system demand in the Benson sub-area was about 2,000 acre-feet and exempt well demand was about 1,800 acre-feet. Approximately 85% of the municipal water demand in the sub-area (3,300 acre-feet) is met by pumping groundwater. About 600 acre-feet of effluent are returned to the aquifer as incidental recharge. In 2002, about 380 acre-feet of effluent was directly used for turf irrigation at the San Pedro Golf Course.

Industrial

For the purposes of this report, industrial water demand is a non-irrigation use of water not served by a city, town or private water company. Industrial water demand in the Basin consists of five sand and gravel facilities, one dairy, an ammonium nitrate manufacturing plant, and three golf courses. All the sand and gravel facilities and two of the industrial golf courses are located in the Sierra Vista sub-area. In 2002, industrial demand in the Sierra Vista sub-area was 1,300 acre-feet. One industrial golf course, the dairy and the ammonium nitrate plant (Apache Nitrogen), are located in the Benson sub-area. All of the industrial facilities in the Basin used approximately 800 acre-feet of groundwater in 2002. Approximately 80 acre-feet of water used for industrial turf irrigation returns to the aquifer as incidental recharge. All current water supplies are groundwater.

Stock

A small volume of groundwater, about 300 acre-feet, was assumed to be used for stockwatering purposes. This information was estimated from a Cochise County total livestock number prorated on a per acre basis for the Basin and split evenly between the sub-areas. A use of 12 gallons per head per day was assumed.

Riparian

The riparian vegetative community along the San Pedro River uses a relatively large amount of water in the Basin. This demand is therefore a critical component of the water budget, yet is among the hardest to estimate. A portion of the water use by the riparian vegetation comes from the aquifer system, and a portion comes from precipitation, post-flood bank storage, and efficient utilization of percolation into the vadose zone (Corell and others, 1996; Chehbouni and others, 2000; Snyder and Williams, 2000).

<u>Sierra Vista Sub-Area</u>

Previous estimates of total evapotranspiration have ranged from about 14,000 acre-feet to 17,000 acre-feet for the portion of the Basin south of Fairbank (Freethey, 1982; Putman and others, 1988; Corell and others, 1996). Some of the total demand is supplied by groundwater, some by surface water, and some by precipitation. A study by the Agricultural Research Service of the U.S. Department of Agriculture (Scott and others, 2004, in preparation) estimates that riparian groundwater use in the Sierra Vista sub-area ranged from 7,330 to 8,970 acre-feet per year for 2003, or an average of 8,150 acre-feet per year. The model calibrated value of 7,700 acre-feet per year of riparian use from Corell and others (1996) was used in this report for the Sierra Vista sub-area because this estimate represented a longer period of time than the three years estimated in the study by Scott and others (2004, in preparation). The 7,700 acre-feet of groundwater demand was about half of the Corell and others (1996) estimate of total riparian demand.

<u>Benson Sub-Area</u>

For the Benson sub-area, total surface water and groundwater use by riparian vegetation had been previously estimated for several studies. Putman and others (1988) estimated total riparian water use at about 16,200 acre-feet per year. Following Corell and others (1996), half this demand was assumed to be supplied by groundwater and half by surface water or precipitation. Thus this estimate was adjusted to 8,100 acre-feet of groundwater demand. Jahnke (1994) estimated total evapotranspiration in the “Benson basin” at about 21,900 acre-feet per year. Jahnke's model-calibrated value for evapotranspiration was 16,200 acre-feet per year. Anderson and Freethey (1994) used a conceptual range of 5,100 acre-feet to 16,700 acre-feet, and simulated 7,100 acre-feet in their model. The Anderson and Freethey model simulation ended in 1977.

Several recently completed studies were used for the estimate of riparian groundwater use in this report. Data from Scott and others (2004, in preparation) was combined with aerial photo analysis by the U.S. Fish and Wildlife Service (2002) to derive estimates of riparian water use for the Benson sub-area. Scott and others estimated the groundwater use by mesquite, cottonwood, willow and other vegetative communities for the San Pedro Riparian National Conservation Area (SPRNCA). Scott and others (2004, in preparation) estimated that about 3,500 acre-feet of groundwater was used by the riparian community within the portion of SPRNCA that lies in the Benson sub-area. For the portion of the

Benson sub-area outside SPRNCA, the community type use rates from Scott and others (2004, in preparation) were combined with acreage estimates for various plant community types from the U.S. Fish and Wildlife Service (2002). Percent canopy cover was estimated from aerial photography (Arizona Regional Image Archive, 2004) for the mesquite vegetative categories that comprised the majority of the riparian acreage.

Salt cedar (*Tamarix sp.*) is found in the Benson sub-area, but not in the Sierra Vista sub-area, and it was necessary to make an estimate for salt cedar use. The consumptive use estimate for salt cedar was taken from work by Dahm and others (2002) along a perennial reach of the Rio Grande in New Mexico. In a setting where depth to water was greater than 4 meters, Dahm reported that the evapotranspiration rate for a dense stand of salt cedar was greatly reduced to half the rate found in a similar stand where the depth to water was two to three meters below land surface. A reduction in demand of 50% was therefore applied to salt cedar along the San Pedro River because of the greater depth to groundwater and intermittent nature of the stream in the Benson sub-area. This reduction was based on information provided during a telephone conversation with Dr. Dahm (May 17, 2004).

The methodology used in estimating groundwater use from the riparian inventory for the Benson sub-area outside of SPRNCA is discussed in Appendix E. An estimate of 6,150 acre-feet of riparian demand was obtained for the Benson sub-area outside of SPRNCA using the data sources and methodology described above, and Scott and others (2004, in preparation) provided an estimate of 3,500 acre-feet for riparian demand for the Benson sub-area within SPRNCA, for a total estimated riparian groundwater demand of 9,650 acre-feet.

Underflow

A very small amount of groundwater flows out of the Benson sub-area at "The Narrows" as underflow. Heindle (1952) estimated 100 acre-feet per year through the Narrows. Geologic mapping by Drewes (1974) shows "The Narrows" as a shallow gap in the Johnny Lyon granodiorite about 200 to 300 feet wide. Freethey and Anderson (1994) estimated an outflow of about 1,100 acre-feet per year based on regional modeling. Their estimate came from a constant head model boundary however, and underlying data assumptions to check the validity of the estimate are not available. A geophysics thesis showing depth to bedrock in the area was also examined (Halverson, 1984). The thesis data are quite extensive to the north and south of "The Narrows," but do not extend into the bedrock area to either side of "The Narrows," shedding no definitive light on the question of underflow. Halverson postulates depths to bedrock of over 1,000 feet to the north and south of "The Narrows," however her contours indicate considerable shallowing as "The Narrows" and adjacent mountain fronts are approached. Drewes (1974) has mapped outcrops of granodiorite in the area of "The Narrows" that indicate alluvial material in the area may be quite shallow. Aquifer test data supplied by The Nature Conservancy at the Three Links Farm (written correspondence from James Lombard to David Harris, The Nature Conservancy, dated August 6, 2003) was also used to estimate underflow through the floodplain alluvium of "The Narrows." This test provided an estimated transmissivity value of 43,000 ft^2/day. This transmissivity value was used at "The Narrows" to estimate underflow using a flow net analysis. A channel width of 300 feet was used together with a water table slope of 25 feet per mile (equal to the slope of the riverbed surface). The resulting underflow estimate shown in the present report is about 200 acre-feet per year leaving the USP Basin at "The Narrows."

Intra-basin Groundwater Transfers

Another groundwater outflow component is the baseflow of the San Pedro River, as measured at the USGS streamgage, "San Pedro River near Tombstone" (#09471550). This outflow is actually a transfer of water from one part of the Basin to another, and as such is reflected in the sub-area budgets, but not in the basin-wide budget. Flow data from 1997 to 2004 show an average non-flood related stream flow leaving the Sierra Vista sub-area of about 3,250 acre-feet per year. Flow diminished rapidly after the winter months, and zero baseflows are generally recorded during late spring, summer and fall. Winter baseflows (November-March) averaged about 3,100 acre-feet per year. An additional 150 acre-feet of baseflow on average left the Sierra Vista sub-area during late spring and early fall. This volume was felt to be used by riparian vegetation before it recharged the groundwater system.

Recharge from baseflow transferring from the Sierra Vista sub-area to the Benson sub-area during the winter (November-March) period of 1996-2003 was estimated at 3,100 acre-feet. This lesser volume was felt to recharge the Benson sub-area groundwater system because the riparian system that might have used this water was dormant. The recharge from baseflow is reflected in the Benson sub-area budget but not in the basin-wide budget for reasons explained above. An additional transfer of about 440 acre-feet per year at the gage site occurs as underflow in the floodplain alluvium (Corell and others, 1996).

3.1.7 Discussion of Groundwater Budget

Identifying major inflows to and outflows from the groundwater system of the USP Basin has allowed construction of the groundwater budget shown in Table 3-2. Table 3-2 presents a groundwater budget for the entire USP Basin as well as for the Sierra Vista sub-area and the Benson sub-area. Mountain front recharge is the major source of recharge to the aquifer in the USP Basin. Infiltration of river flows is another major source of recharge. Evapotranspiration by riparian vegetation is a major groundwater use in the Basin as a whole. These components are among the most difficult water budget components to measure.

The groundwater budget shown in Table 3-2 for the Sierra Vista sub-area is based on a number of scientific studies over a number of years, and is relatively well understood. Estimates of both mountain front recharge and riparian use, while difficult to directly measure, are more firm in the Sierra Vista sub-area, which has been more thoroughly studied and where the hydrologic conditions lend themselves to better data collection. In the Benson sub-area, fewer studies, less data and more complex hydrologic conditions make the estimates presented less certain than in the Sierra Vista sub-area.

The groundwater budget for the Benson sub-area was constructed with the assumption of little groundwater outflow northward out of the sub-area, which in turn implies that consumption of groundwater is greater than recharge for the area. The USGS gage, "San Pedro River near Benson," also referred to as "The Narrows" was operational from 1967 to 1976, and the gage data showed little or no baseflow leaving the groundwater basin most days of most years. This indicates that the groundwater budget outflows are greater than the inflows for the Benson sub-area. The water budget in Table 3-2 reflects this.

The change in groundwater storage estimate is the difference between total inflow and total outflow for the Basin or sub-area. In the Sierra Vista sub-area the change in groundwater storage is about –8,350 acre-feet per year. The water budget for this sub-area includes a transfer of 3,250 acre-feet of baseflow to the Benson sub-area. The Benson sub-area shows a change in groundwater storage of –1,320 acre-feet.

Both the estimate of total inflow (35,750 acre-feet per year) and total outflow (45,270 acre-feet per year) for the Upper San Pedro Basin do not include the exchange of baseflow and underflow between the Sierra Vista and Benson sub-areas. For this reason one cannot simply add up the change in storage for both sub-areas and find the total basin change in storage. The annual change in storage for the Upper San Pedro Basin is about –9,520 acre-feet per year. Total groundwater in storage in the Upper San Pedro Basin is estimated at about 20 to 26 million acre-feet.

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Table 3-2. Average Annual Groundwater Budget for the USP Basin, ca 2002.

Inflows to Groundwater System	Sierra Vista Sub-area	Remarks	Benson Sub-area	Remarks
Mountain Front, Ephemeral Channel, Cross-border Flux	18,000	From Corell and others (1996). Adjusted to eliminate Greenbush Draw recharge.	10,600	Average of estimates: ADWR HSR (1991a) Jahnke (1994) Anderson and Freethey (1994)
Artificial Recharge	1,500	Table 4-7	0	Table 4-7
Incidental Recharge	2,000	Table 4-7	600	Table 4-7
Baseflow and Underflow into Sub-area*	---	Included with mountain front recharge estimate	440 3,100 3,050	Model underflow from Corell and others (1996) Baseflow data at USGS Tombstone and "The Narrows" gages** Flood recharge estimated from USGS gage data**
Total Inflow	**21,500**		**17,790**	

Outflows from Groundwater System	Sierra Vista Sub-area	Remarks	Benson Sub-area	Remarks
Agricultural Demand	2,500	Table 4-7	5,000	Table 4-7
Municipal Demand	14,500	Table 4-7 -excludes effluent	3,300	Table-4-7 excludes effluent
Industrial Demand	1,300	Table 4-7	800	Table 4-7
Stock Demand	160	Table 4-7	160	Table 4-7
Riparian Use	7,700	50% of total riparian demand, from Corell and others (1996)	9,650	From ARIA (2004) and USFWS (2002); use rates from Scott and others (2004) and Dahm and others (2002)
Underflow from Sub-area*	440	At Tombstone gage site. From Corell and others (1996)	200	Underflow through "The Narrows" from flow net analysis
Baseflow Out*	3,250	At Tombstone gage site for 1997-2003. From USGS gage data***	NA	From USGS gage records at Benson ("The Narrows")
Total GW Demand	**29,850**		**19,110**	
Change in Storage	**-8,350**		**-1,320**	

NOTE: All values are in acre-feet per year. Estimates are shown to the nearest 10 acre-feet for calculation purposes, but should not be considered this accurate.

BASIN TOTALS

* Estimates of total inflow and total outflow for the entire Basin do not include transfer of baseflow and underflow between the Sierra Vista and Benson sub-areas.

** Includes 3,100 acre-feet of recharge from baseflow from the Sierra Vista sub-area and 3,050 acre-feet of recharge from flood events in the Benson sub-area. The 3,100 acre-feet does not appear in the basin-wide water budget as recharge because it represents a transfer of water within the Basin groundwater system; not an addition of water to the aquifer.

*** Average baseflow at the Tombstone gage for 1997-2003. Based on flows for non-flood influenced months between September and May of this period.

Total Inflow	+35,750
Total Outflow	-45,270
CHANGE IN STORAGE	**-9,500** ***(rounded)***

3.2 Land Subsidence

The second factor that the director must consider to determine whether to designate an AMA is whether "land subsidence or fissuring is endangering property or potential groundwater storage capacity." A.R.S. § 45-412(A.2). There are limited data available to the Department for this determination within the USP Basin.

Land subsidence is a gradual settling or sudden sinking of the Earth's surface owing to subsurface movement of earth materials (U. S. Geological Survey, 1999). This subsidence may be caused by such factors as aquifer-system compaction, drainage of organic soils, underground mining (e.g. at Tombstone), hydrocompaction, natural compaction, sinkholes, and thawing permafrost (National Research Council, 1991). The type of subsidence considered in this document is aquifer-system compaction caused by groundwater pumping.

When water is extracted from the ground at rates greater than it is recharged, there is a lowering of the water table (unconfined aquifer system) or a lowering of the potentiometric surface (confined or artesian aquifer system). When the stress applied to these systems exceeds the pre-consolidation stress threshold, the fine-grained constituents can be rearranged and become packed more closely together. This subsurface compaction of material causes the land surface to subside. If the aquifer system is primarily coarse-grained material it is possible that an increase in stress can be supported by grain-to-grain contact, without rearrangement and without land subsidence.

The two primary factors controlling whether subsidence will occur, and if so the amount of the subsidence, are the magnitude of the water table change or lowering of the potentiometric surface, and the percentage of fine-grained material (clays/silt) within the aquifer system. Within areas of central and southern Arizona there have been declines in the water table of several hundred feet or more. In some of these areas the aquifer system is composed of thousands of feet of unconsolidated gravel, sand, silt, and clay. Land subsidence has occurred in basins in which water levels have declined several hundred feet and, which also contain basin-fill deposits having a relatively high silt and clay content.

<u>Sierra Vista Sub-Basin</u>

The potential for land subsidence exists within the Sierra Vista sub-basin if the conditions discussed above are met. Currently a land subsidence monitoring network is not in place within the Sierra Vista sub-basin; however, the USGS has established a network of gravity/GPS stations within certain areas of the sub-basin that could be used as part of a subsidence monitoring network. There are no known documented occurrences of land subsidence caused by aquifer system compaction (personal commun. with Ray Harris, Arizona Geological Survey, Tucson, AZ, and Don Pool, U.S. Geological Survey Hydrologic Investigations and Research Program, Tucson, AZ, 2002). Subsidence does not seem likely for most portions of the Sierra Vista sub-basin given the comparatively small water-level changes from pre-development conditions. At this time, neither land subsidence nor fissuring is endangering property or potential groundwater storage.

Allen Flat Sub-Basin

Specific land subsidence information is not available for the Allen Flat sub-basin. A crucial factor in land subsidence depends on significant groundwater withdrawals. There is little groundwater use in the Allen Flat sub-basin and subsidence from aquifer system compaction caused by groundwater pumping would not be expected to occur in this area.

3.3 Water Quality

The last factor that the director must consider to determine the need for an AMA, is whether "use of groundwater is resulting in actual or threatened water quality degradation." A.R.S. § 45-412(A.3). In order to make this determination the Department evaluated water quality data for the Sierra Vista sub-basin and the Allen Flat sub-basin.

Sierra Vista Sub-Basin

Groundwater quality in the Sierra Vista sub-basin has been evaluated and documented in several reports by a number of investigators (Bryan and others, 1934; Heindl, 1952; Brown and others, 1966; Roeske and Werrell, 1973; Konieczki, 1980; Thompson and others, 1984; Barnes, 1997; Coes and others, 1999; Pool and Coes, 1999; Arizona Department of Environmental Quality, 2000; and Cordy and others, 2000). The reports give a general description of the geochemistry of groundwater in the sub-basin.

Water in the regional (basin-fill) aquifer is predominantly a calcium-bicarbonate type with total dissolved solids (TDS) in the range of 200 to 400 milligrams per liter (mg/L) (Thompson and others, 1984; Konieczki, 1980). Along the San Pedro River near Palominas, between Hereford and Lewis Springs, and between St. David and "The Narrows," groundwater evolves to a sodium bicarbonate and sodium-sulfate type water, with TDS rising to greater than 1,000 mg/L in some cases. These areas of elevated TDS generally correspond to the confined areas of the regional aquifer.

Heindl (1952) found that shallow groundwater was higher in TDS than groundwater at depths greater than 600 feet and was calcium-sulfate or sodium sulfate type water. Previous investigators noted elevated fluoride concentrations in the St. David-Benson area (Bryan and others, 1934; Thompson and others, 1984) and elevated sulfate concentrations in the St. David-Pomerene area (Roeske and Werrell, 1973; Thompson and others, 1984). Later investigations by the USGS and the Arizona Department of Environmental Quality (ADEQ) report findings similar to the earlier studies (Coes and others, 1999; Pool and Coes, 1999; and Cordy and others, 2000).

The USGS and ADEQ conducted a cooperative water-quality assessment of the Sierra Vista sub-basin of the USP Basin (Coes and others, 1999). Thirty-nine groundwater samples were collected in 1996 - 1997 and analyzed for general mineral constituents, physical and chemical characteristics, nutrients, and trace constituents. The results were compared to U.S. Environmental Protection Agency primary and secondary maximum contaminant levels (MCLs) for drinking water. Primary MCLs are enforceable, health-based standards that specify the maximum concentration of a constituent that is allowed in a public water system. Secondary MCLs are unenforceable standards that are generally related to aesthetics. The effects of location, well depth, aquifer type, geology, and land use on the results were evaluated. The data set was compared to a historical data set from 1950 – 1965.

Coes and others (1999) concluded that groundwater in the Basin is suitable for all water uses. Only one sample (4.5 mg/L fluoride) exceeded the primary MCL of 4 milligrams per liter (mg/L) fluoride. Several samples exceeded secondary MCLs for fluoride, iron, manganese, sulfate, TDS, and pH. The report noted that the concentrations of chemical constituents that exceeded MCLs and variations in quality could be attributed to natural geochemical reactions and/or associated with corroding well casing.

Arsenic was detected in about 35% of the groundwater samples collected by Coes and others (1999); all of these samples met the current 50 part per billion (ppb) standard. The U.S. Environmental Protection Agency now requires public water systems to lower the allowable arsenic content in drinking water from 50 ppb to 10 ppb by January 23, 2006 (Arizona Department of Environmental Quality, 2003a). Four of the samples collected by Coes and others (1999) had arsenic concentrations exceeding the new standard of 10 ppb, with arsenic levels ranging from 11 to 33 ppb. These samples were collected about three miles northwest of Tombstone (two samples), about ten miles northeast of St. David near the Dragoon Mountains, and about two to three miles southwest of “The Narrows” (Coes and others, 1999). In addition, between 1996 and 2004, six Benson City wells, two Pomerene Domestic Water User Association wells, three Tombstone City wells, two Cochise Junior College wells and three Apache Nitrogen Product wells were identified as having arsenic levels above the new standard of 10 ppb (Arizona Department of Environmental Quality, 2004). With the exception of the Tombstone City wells, all of the arsenic exceedences are in the Benson sub-area.

Consistent with previous investigations, Coes and others (1999) found that groundwater in the Sierra Vista sub-basin is a calcium-bicarbonate type. TDS ranged from 131 mg/L to 1,250 mg/L. Statistically significant variations in groundwater quality versus well depth, well location, and aquifer type were identified. Sodium concentrations are generally higher in the basin-fill aquifer in the St. David area than in the southern half of the Basin. Temperature, pH, and calcium concentrations varied with well depth. Temperature and pH generally increases with depth. Calcium concentrations generally decrease with depth. No statistically significant differences were identified between groundwater quality and geology, land use, or with time (Coes and others, 1999).

A hydrogeologic investigation of the Sierra Vista sub-basin (Pool and Coes, 1999) was conducted by the USGS concurrently with the groundwater quality assessment (Coes and others, 1999). Groundwater samples from the water quality assessment and additional samples collected were used to define groundwater flow paths and quantify the sources of base flow to the San Pedro River above the Charleston gage. Additional data analysis included stable isotopes of hydrogen and oxygen, and tritium concentrations.

Specific conductance was measured in groundwater and found to be quite variable. Specific conductance is a measure correlated to TDS. Specific conductance was generally higher in the floodplain alluvium than other water sources, averaging 558 microsiemens per centimeter (µS/cm) and 550 µS/cm, respectively. The cause of the elevated specific conductance (or TDS) is poorly understood, but can be attributed to evaporative concentration, infiltration of high TDS surface flow, and dissolution of gypsum in the regional aquifer. An extensive record of specific conductance at the Charleston streamgage indicates that runoff is not a likely source of the elevated TDS (Pool and Coes, 1999).

Contamination from mining, municipal, industrial, military, and commercial activities throughout the Basin could potentially threaten groundwater resources, however, the threats are localized. These include releases from the copper mines in Cananea, Mexico, and Bisbee, Arizona; cyanide leaching solution spills into Walnut Gulch; sanitary sewer overflows discharging to tributaries of Greenbush Draw from Naco, Sonora; contamination from septic systems; and industrial contamination from past activities at Apache Powder and Fort Huachuca.

Tailings ponds associated with Phelps Dodge Corporation's mining operations at Bisbee are located in the headwater of a tributary to the San Pedro River. Leaks and spills from these operations can potentially contaminate groundwater. However, Phelps Dodge has applied for an Aquifer Protection Permit from the ADEQ, the agency responsible for water quality regulation and enforcement. The application is currently under review and is expected to be issued in mid-2005. (E. Wilson, Arizona Department of Environmental Quality, personal commun., February 2005).

Mine infrastructure improvements in Cananea have significantly reduced, if not eliminated, releases from Mexico since the late 1980s. This threat is monitored by ADEQ with a six station network of monitoring sites (H. Huth, Arizona Department of Environmental Quality, personal commun., February 2005). Several abandoned mill sites, remnants of historic mining in Tombstone, exist along the San Pedro River. There is no known documentation of water quality associated with these sites, yet the potential for adverse impacts exists (Jim Leenhouts, U.S. Geological Survey, written commun. Feb.10, 2004).

The City of Naco, Sonora has received assistance from the North American Development Bank to upgrade its sewage lagoons, which were completed in 2003. The treatment facility is currently operating at the plant capacity of 250,000 gallons per day (C. Tinney, Arizona Department of Environmental Quality, personal commun., February 2005).

Untreated releases have entered the United States into tributaries of Greenbush Draw, but have been significantly curtailed with plant modifications.

The City of Bisbee is operating under an ADEQ Consent Order to address wastewater collection and treatment system inflow/infiltration and effluent quality issues (www.epa.gov/region09/border/bisbee/index.html). In addition, the EPA has issued a Finding of Violation and Notice for Compliance to address discharge permit violations. Some parts of the collection system are old and in poor condition, resulting in sewer overflows. Exceedances of treatment plant capacity have resulted in releases of raw or partially treated sewage. The City of Bisbee was awarded a Border Environment Infrastructure Fund grant in September 2003, which along with other financial sources will provide funds to repair the collection system and consolidate wastewater treatment, now done at three separate wastewater treatment plants (WWTP), at the San Jose WWTP. Plans are to treat the wastewater to sufficient quality to irrigate the Turquoise Valley Golf Course in Naco, and when irrigation needs are low, to put excess wastewater into Greenbush Draw.

A number of communities such as Palominas, Hereford, St. David, and Pomerene do not have centralized wastewater treatment systems and rely on septic tanks and leach fields for waste disposal. These septic systems and leach fields pose a potential localized threat to water quality (C. Tinney, Arizona Department of Environmental Quality, personal commun., February, 2005).

The Apache Powder Superfund Site is located approximately 2.5 miles southwest of St. David and is bounded by the San Pedro River on the east. Apache Nitrogen Products, Inc. (ANP), formerly known as Apache Powder Company, owns and operates a fertilizer and nitric acid manufacturing plant at the site. Soil, groundwater and surface water contamination has occurred due to past manufacturing and disposal practices at the site. Sampling has identified a nitrate contaminated plume at the site affecting both groundwater and a short reach of the San Pedro River. Additional contaminants of concern at the site include arsenic, fluoride, perchlorates and metals (Arizona Department of Environmental Quality, 2003b). Cleanup efforts to date include removal of waste barrels and contaminated soils, and construction of a treatment wetland. A future cleanup schedule has been developed by ANP and remedial activities are being coordinated with the EPA and ADEQ.

Several environmental cleanups involving contaminated soils have been performed at Fort Huachuca, but no groundwater problems have been identified. These sites are part of the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) cleanup funded by the Department of Defense Installation Restoration Program. Groundwater monitoring wells have been installed at the South Range Landfill and the East Range Mine Shaft and are periodically sampled to monitor for contamination. No groundwater contamination has been detected at either location (www.azdeq.gov/environ.waste/sps/statesites.htm#fthcha; B. Stonebrink, Arizona Department of Environmental Quality, personal commun., February, 2005).

A review of ADEQ's leaking underground storage tank (LUST) database (Arizona Department of Environmental Quality, 2003c) indicates that 278 incidents have occurred within the Basin since 1985, of which 34 sites are currently under investigation. While these LUST sites pose a potential localized threat to groundwater, the threat is not regional in nature.

In summary, while a number of localized water quality problems exist in the Sierra Vista sub-basin, the use of groundwater is not resulting in actual or threatened water quality degradation in the sub-basin. Local water quality problems are being addressed through local, state and federal efforts.

<u>Allen Flat Sub-Basin</u>

Groundwater quality of the Allen Flat sub-basin was investigated by Burtell (1989). In that study, samples from 34 wells and springs were examined for major ion and silica concentrations. The results indicated that the dominant water type was calcium-bicarbonate ($Ca\text{-}HCO_3$) however, sodium bicarbonate ($Na\text{-}HCO_3$) waters were detected in eleven samples. In general, Burtell (1989) identified the groundwater of Allen Flat as good quality water.

In an effort to further characterize the groundwater quality, Burtell estimated the TDS by summing the concentrations of SiO_2 and major ions. Five of Burtell's samples were above 500 mg/l TDS. Four of these samples came from mountain-front wells where the dissolution of natural minerals is possibly contributing to the elevated TDS levels. The fifth however, came from a well located within 25 yards of a ranch house septic system. Three other wells are located within 75 yards of a septic system. All four of these wells produced samples with nitrate (NO_3^-) levels in excess of the representative background level of 10 mg/l; water from one well exceeded the drinking water standard of 45 mg/l (Burtell, 1989). Although not sampled in the study, there is also the possibility that other constituents (organic compounds, bacteria, and trace metals) may be leaching from septic systems in the area and potentially contaminating groundwater. Contamination from septic system leachate could become a more serious problem if the Allen Flat sub-basin is further developed and required setbacks of wells from septic tanks are not followed.

3.4 Summary

This section summarizes the hydrologic conditions in the USP Basin. Continued groundwater withdrawals in excess of recharge will impact the groundwater resources of the Basin. The magnitude and extent of these impacts depend on a number of factors including population growth, water demand rates, conservation efforts, effluent recharge, location of groundwater use, mountain front recharge and climate.

The upper and lower alluvial aquifers contain an estimated 15.6 million acre-feet of groundwater. The Pantano (?) Formation contains between an estimated 3.8 million to

10.1 million acre-feet of water, and the floodplain aquifer contains an estimated 421,000 acre-feet of water. Thus, total groundwater storage in the Sierra Vista sub-basin is estimated to range between 20 million and 26 million acre-feet. These estimates are based on gravity studies by Gettings and Houser (2000) and Oppenheimer and Sumner (1980), on year 2001-2002 groundwater level data from the Department's GWSI database (Arizona Department of Water Resources, 2002b), and specific yield estimates are from Gettings and Houser (2000), Corell and others (1996), and from hydrologic literature. The annual change in groundwater storage for the USP Basin is about –9,500 acre-feet per year (Table 3-2).

Three deep alluvial troughs were identified in the Sierra Vista sub-basin by Gettings and Houser (2000), Halverson (1984), and Oppenheimer and Sumner (1980). Two of the structural troughs are located west of the San Pedro River and are north and south of Sierra Vista. A shallow area of hardrock trending east-west under Fort Huachuca, Sierra Vista, and Charleston separates two of the deep troughs to the north and south. The third trough is east of the San Pedro River and northwest of Tombstone.

Between 1990 and 2001, the Sierra Vista cone of depression deepened slightly. The area within the cone of depression showed declines generally between 5 and 10 feet between 1990 and 2001 (see Figure 3-11), or between 0.5 to 1.0 foot per year (Barnes and Putman, 2004). An average groundwater decline rate of 1.4 feet per year was reported by Putman and others (1988) for this same area between about 1968 and 1986.

In other areas of the USP Basin, groundwater-level changes between 1990 and 2001 have ranged from a rise of 11 feet northwest of Pomerene to a decline of 32 feet west of Naco. Figure 3-11 shows water-level changes within specific areas of the Basin for the 12-year period from 1990 through 2001.

Cones of depression appear to be developing in an area near Benson along Interstate 10 and southwest of Bisbee along Greenbush Draw. These cones are found close to well fields that supply municipalities.

The artesian heads present in some portions of the regional aquifer underlying the floodplain alluvium of the San Pedro River have decreased somewhat over time due to groundwater development in these areas. In the Benson-Pomerene area, Barnes and Putman (2004) reported a modest water-level decline in the deeper (artesian) aquifer. Artesian conditions continue to support modest groundwater discharges to wells in the Benson-Pomerene areas. Artesian conditions also exist in the Palominas-Hereford area but aquifer pressures were never sufficient for large-scale irrigation in this area (Bryan and others, 1934). Barnes and Putman (2004) report little change in water levels in wells in the Palominas-Hereford area.

The shallow floodplain aquifer, which underlies the San Pedro River, has shown no long-term declines in water level. This aquifer is sustained by groundwater discharge from the basin-fill aquifer and recharge from flood events. The recent drought conditions have reduced flow in the river, thus limiting recharge to the shallow floodplain aquifer and contributing to some observed short-term declines (Barnes and Putman, 2004).

No land subsidence has occurred in the USP Basin to date (personal commun. with Ray Harris, Arizona Geological Survey, Tucson, AZ and Don Pool, U.S. Geological Survey Hydrologic Investigations and Research Program, Tucson, AZ, 2002). Putman and others (1988) reported a similar finding of no land subsidence in the USP Basin.

There are no known regional water quality problems in the USP Basin from the use of groundwater. There are several local problems due to industrial, mining, municipal and military activities. Putman and others (1988) reported no known regional water quality problems in the Basin, and similarly identified local water quality problems.

CHAPTER 4

CULTURAL WATER DEMAND AND SUPPLY

4.1 Overview

This Chapter discusses the historic, current and projected cultural water demand in the USP Basin. Evaluation of water demand as it relates to sufficiency of Basin water supplies was a primary focus of this review. Natural demands, including evapotranspiration from riparian vegetation along the San Pedro River (River), is a factor in the hydrologic budget, which is discussed in Chapter 3.

The Department conducted a thorough investigation of water demand and supply. Due to a lack of metered water use data for the Basin, it was necessary to estimate usage in some cases. Assumptions used to generate water demand estimates and projections are discussed in this Chapter, and more detailed information is contained in Appendices F through L. A projection period to 2030 is used in this report.

Because of the diversity of water demand, hydrology and population characteristics between the northern and southern parts of the Basin, for the purposes of this report, data are presented not only for the entire Basin, but, also separately for two informal Basin divisions, the Sierra Vista sub-area and the Benson sub-area. These sub-areas are described in Chapter 3 and are depicted in Figure 3-2.

4.1.1 Demographics

The year 2000 Census population of the Basin, including that part of Bisbee located outside of the Basin boundaries but served by wells located within the Basin, was almost 80,000. Residents residing in incorporated areas accounted for 65% of the Basin population. Populations of incorporated cities and towns and unincorporated areas in the year 2000 are shown in Table 4-1.

Between 1990 and 2000, Benson, Tombstone and Sierra Vista grew by 23-25%. Bisbee and Huachuca City each experienced slight population declines during this ten-year period. During the period 1990-2000, the population of the Basin increased an average of 2.3% per year compared to 2.5% in the Tucson area and 3.8% in the Phoenix metropolitan area.

The average age of the Basin population is getting older. In Benson and Sierra Vista, the fastest growing population segment between 1990 and 2000 was the age group 65 and older, reflecting an influx of retirees. In Sierra Vista, the 65 and older age group increased by 90.5% between 1990 and 2000 (The Indicator, 2003).

Department of Economic Security (DES) projections for the USP Basin are used in this report with an adjustment as discussed in section 4.2.2. These official DES projections predict a linear future growth rate of 1.1% per year, for a total of 110,000 people by 2030. Projections based on the growth rate between 1990 and 2000 of 2.3% per year result in a population of over 160,000 (including all of Bisbee).

Table 4-1. 2000 Census Population of Incorporated Cities, Towns and Unincorporated Area Using Water Pumped or Diverted within the USP Basin.

PLACE	2000 POPULATION
Benson	4,711
Bisbee	6,090
Fort Huachuca	8,413
Huachuca City	1,751
Sierra Vista	29,362
Tombstone	1,504
Sub-total	51,831
Unincorporated	28,113
Total	**79,944**

The primary economic sectors in the Basin are government, trade and service. Apache Nitrogen and Arizona Electric Power Cooperative are the major employers in the Benson sub-area (Arizona Department of Commerce, 2004a) and agriculture is a significant economic component. Much of the population of the Sierra Vista sub-area is associated with the activities at Fort Huachuca, including active duty military, retirees, contractors, civilian employees and workers that are employed in service jobs off the base. Approximately 11,000 military and civilian employees are associated with the Fort although the City and County are pursuing "an aggressive program of economic diversification" (Arizona Department of Commerce, 2004b).

There are a substantial number of large acreage parcels in the Basin, primarily outside of incorporated areas. The result is the need for individual domestic wells to provide water to households. Based on ADWR records, there were approximately 3,200 active domestic wells in the Basin in 2002. These wells served an estimated 14,400 people, or 17.5% of the total population. High concentrations of domestic wells exist southeast of Sierra Vista north of Hereford Road, south of Sierra Vista and in the Saint David/Benson area. Most wells used for domestic purposes are "exempt wells," defined in the Groundwater Code as a well with a pump capacity of less than 35 gallons per minute. The term "exempt" refers to the fact that withdrawal of water from these wells in AMAs is generally exempt from regulation. A.R.S.§ 45-454.

Figures 4-1 through 4-3 show the number and location of all well permits and well registration filings issued in the USP Basin over time. Shown are both "exempt" wells and "non-exempt wells". Figure 4-1 shows the well permits issued prior to 1980 by the Arizona State Land Department and the Arizona Water Commission, predecessors to the Department. Figures 4-2 and 4-3 show the number and location of well registration filings in the USP basin between 1980 and 2000, including the well permits issued prior to 1980. Not all wells that were issued registrations have been drilled (Arizona Department of Water Resources, 2002c).

4.1.2 Water Demand and Supply

The primary water supply in the Basin is groundwater pumped from wells. Surface water from the San Pedro River is an agricultural supply in the Benson sub-area and surface water diverted from springs in the Huachuca Mountains is used by the City of Tombstone. Some surface water may also be diverted from the Babocomari River. The only other water supplies are effluent and captured rainwater.

The Department found that total cultural water demand in the Basin in 2002 was approximately 31,100 acre-feet. About 19,100 acre-feet of this demand was in the Sierra Vista sub-area and the remaining 12,000 acre-feet of demand was in the Benson sub-area.

An estimated 27,820 acre-feet of groundwater was pumped in 2002 of which 23,600 acre-feet did not return to the aquifer through incidental or artificial recharge. Incidental recharge is water returned indirectly to the aquifer after use, primarily from septic systems, golf course and park irrigation and from effluent discharge. Artificial recharge is water that returns to the aquifer through an underground storage facility, usually through a specially constructed recharge basin. Almost all water that returns to the aquifer through incidental and artificial recharge originates from groundwater withdrawal and use, and offsets some groundwater demand. The groundwater demand that is not offset is referred to as “net use” groundwater in this report.

In 2002, about 8% of the total cultural water demand in the Basin was met by diverting surface water. About 2,800 acre-feet of surface water were diverted from the San Pedro River in the Benson sub-area for agricultural use by the Saint David Irrigation District and the Pomerene Water Users Association. The actual annual amount available for diversion varies depending on weather conditions. Of the volume diverted, it is estimated that about 2,300 acre-feet were consumptively used by crops. In the Sierra Vista sub-area, the City of Tombstone used approximately 160 acre-feet of surface water diverted from springs in the Huachuca Mountains and carried by pipeline to Tombstone.

In 2002, effluent production in the Basin was approximately 5,300 acre-feet, 90% of which was produced in the Sierra Vista sub-area (see Table 6-5). Effluent from the Sierra Vista and Benson Wastewater Treatment Plants was used for irrigation as a method of disposal until 2002 but is now being delivered for golf course irrigation and for groundwater recharge. About 800 acre-feet of effluent was delivered for golf course irrigation in both sub-areas in 2002. It is estimated that approximately 1,500 acre-feet of effluent was recharged through constructed basins in the Sierra Vista sub-area in 2002.

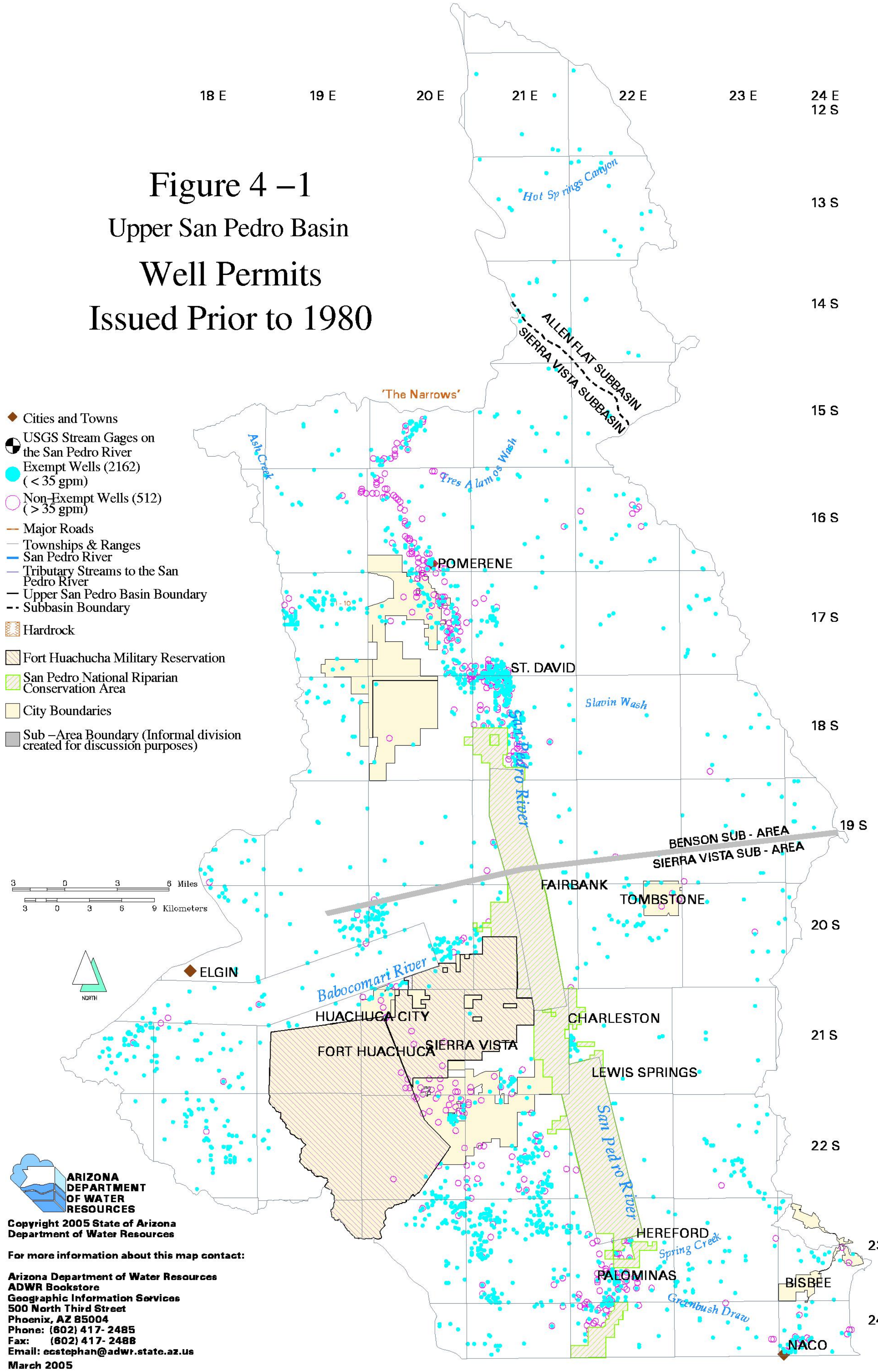

Figure 4 –1
Upper San Pedro Basin
Well Permits
Issued Prior to 1980
18 E
19 E
20 E
21 E
22 E
23 E
24 E
12 S
13 S
14 S
15 S
16 S
17 S
18 S
19 S
20 S
21 S
22 S
23 S
24 S
Hot Springs Canyon
ALLEN FLAT SUBBASIN
SIERRA VISTA SUBBASIN
'The Narrows'
Ash Creek
Tres Alamos Wash
POMERENE
I - 10
ST. DAVID
Slavin Wash
San Pedro River
BENSON SUB - AREA
SIERRA VISTA SUB - AREA
FAIRBANK
TOMBSTONE
ELGIN
Babocomari River
HUACHUCA CITY
FORT HUACHUCA
SIERRA VISTA
CHARLESTON
LEWIS SPRINGS
HEREFORD
Spring Creek
PALOMINAS
Greenbush Draw
BISBEE
NACO
Cities and Towns
USGS Stream Gages on the San Pedro River
Exempt Wells (2162) (< 35 gpm)
Non-Exempt Wells (512) (> 35 gpm)
Major Roads
Townships & Ranges
San Pedro River
Tributary Streams to the San Pedro River
Upper San Pedro Basin Boundary
Subbasin Boundary
Hardrock
Fort Huachucha Military Reservation
San Pedro National Riparian Conservation Area
City Boundaries
Sub –Area Boundary (Informal division created for discussion purposes)
3 0 3 6 Miles
3 0 3 6 9 Kilometers
NORTH
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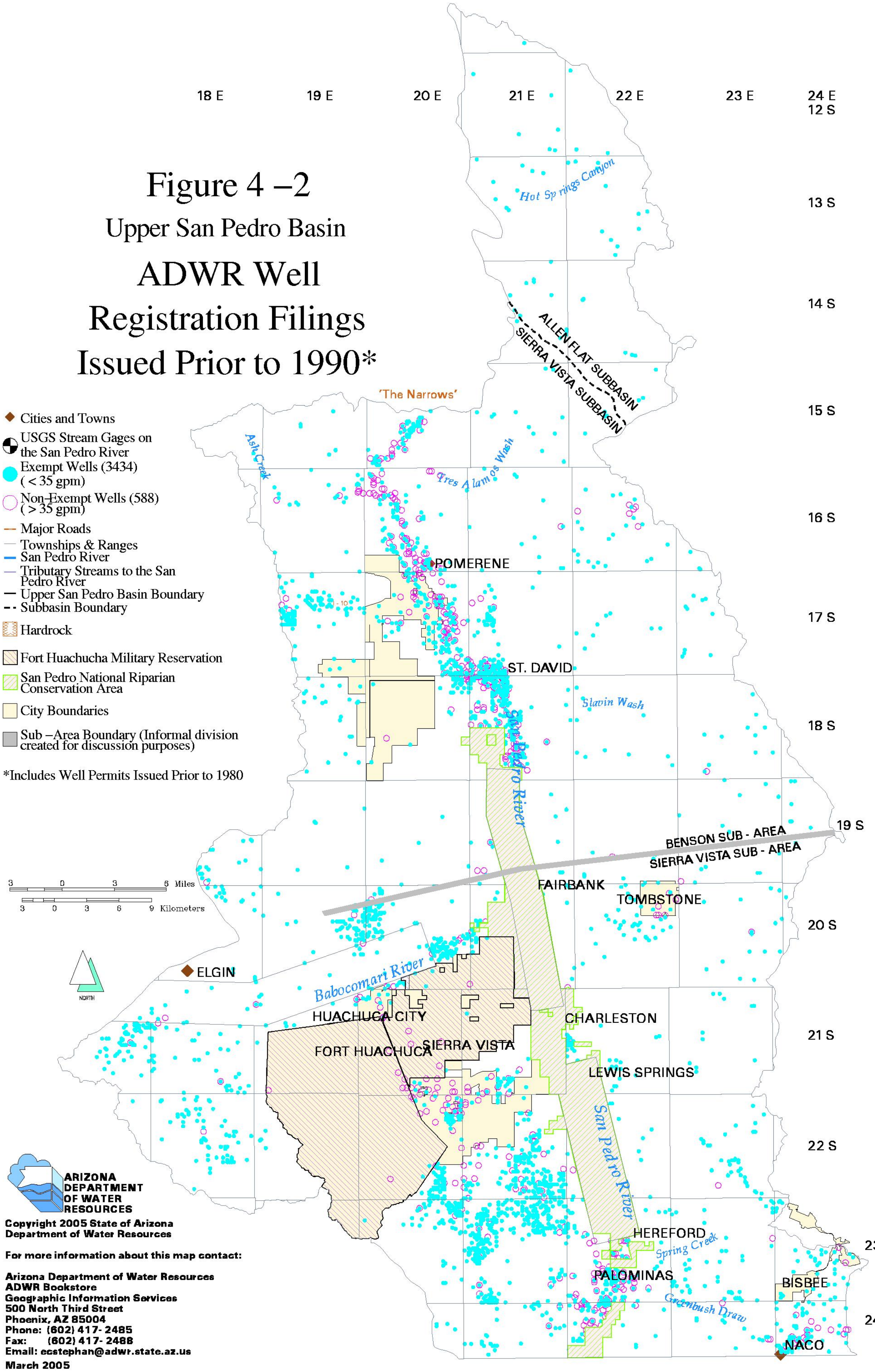
Figure 4 –2
Upper San Pedro Basin
ADWR Well
Registration Filings
Issued Prior to 1990*
Cities and Towns
USGS Stream Gages on the San Pedro River
Exempt Wells (3434) (< 35 gpm)
Non-Exempt Wells (588) (> 35 gpm)
Major Roads
Townships & Ranges
San Pedro River
Tributary Streams to the San Pedro River
Upper San Pedro Basin Boundary
Subbasin Boundary
Hardrock
Fort Huachuca Military Reservation
San Pedro National Riparian Conservation Area
City Boundaries
Sub –Area Boundary (Informal division created for discussion purposes)
*Includes Well Permits Issued Prior to 1980
Miles
Kilometers
NORTH
18 E
19 E
20 E
21 E
22 E
23 E
24 E
12 S
13 S
14 S
15 S
16 S
17 S
18 S
19 S
20 S
21 S
22 S
23 S
24 S
Hot Springs Canyon
ALLEN FLAT SUBBASIN
SIERRA VISTA SUBBASIN
'The Narrows'
Ash Creek
Tres Alamos Wash
POMERENE
ST. DAVID
Slavin Wash
San Pedro River
BENSON SUB - AREA
SIERRA VISTA SUB - AREA
FAIRBANK
TOMBSTONE
ELGIN
Babocomari River
HUACHUCA CITY
FORT HUACHUCA
SIERRA VISTA
CHARLESTON
LEWIS SPRINGS
HEREFORD
Spring Creek
PALOMINAS
Greenbush Draw
BISBEE
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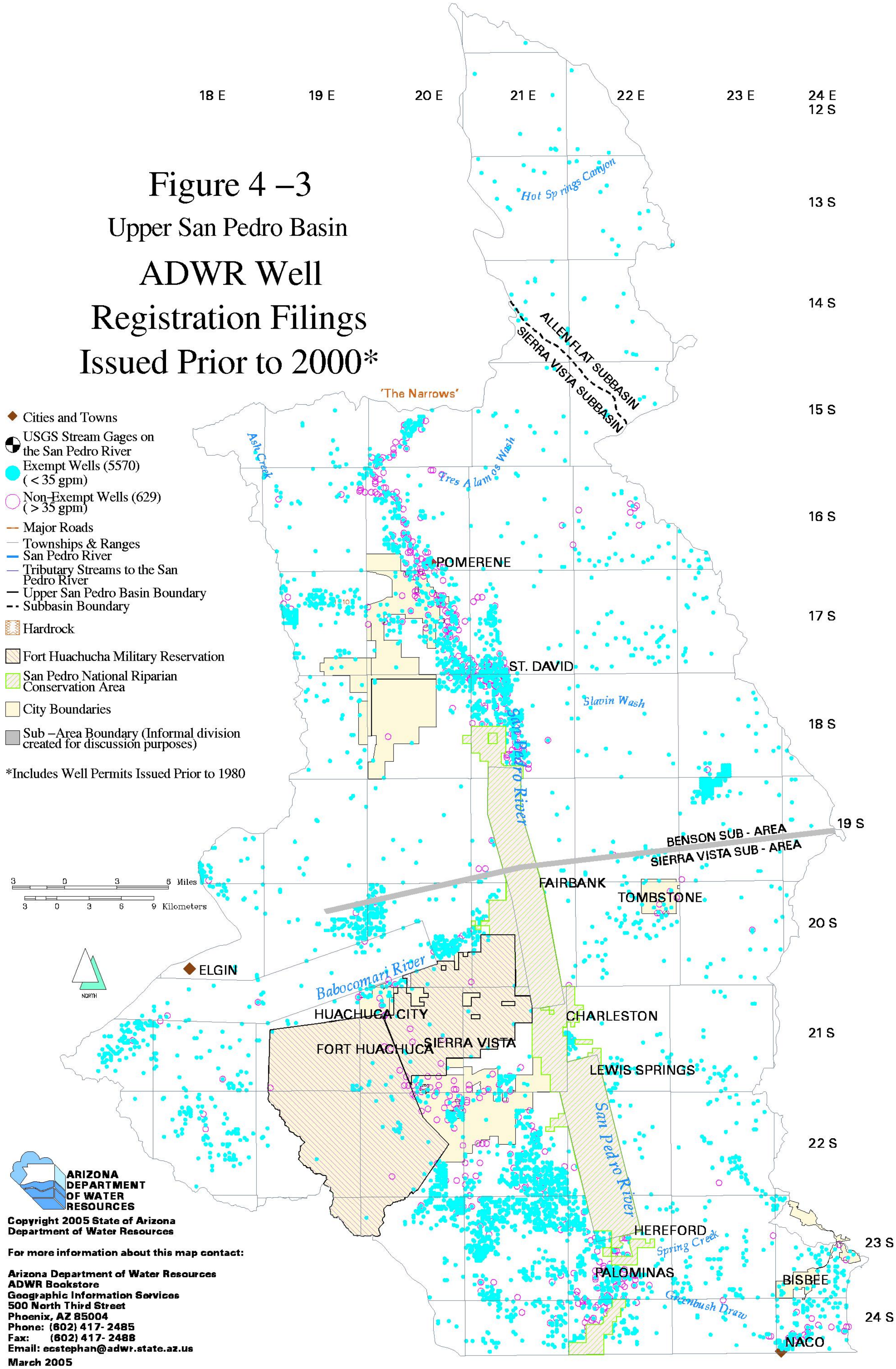


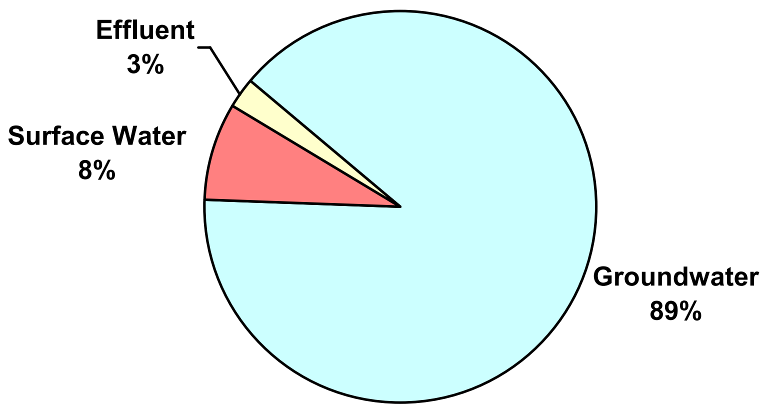
Figure 4 –3
Upper San Pedro Basin
ADWR Well Registration Filings Issued Prior to 2000*

based on estimates in the July, 2002 Fort Huachuca Programmatic Biological Assessment and the ADWR Annual Underground Storage Facility Report, 2002. Effluent is being recharged for the benefit of the aquifer, and there are no known plans to recover it in the future.

Effluent is an increasing water supply and plans are underway to increase its utilization in the future. In the Bisbee area these plans include consolidation of the three treatment plants that serve Bisbee, improvements to the collection system, connection of additional residents to the sewer system and effluent reuse. (see section 4.2.2). In addition, discussions are underway to transport and recharge 200 acre-feet of Huachuca City effluent at the Fort Huachuca recharge facility. USP Basin effluent production in 2030 is projected to be approximately 7,700 acre-feet and, if all these effluent utilization plans are realized, about 7,300 acre-feet would be recharged or used directly. Additional information on incidental recharge assumptions and effluent production are found in Appendix F.

The percentage of each type of water supply used in 2002 is shown in Figure 4-4.

Figure 4-4. Water Demands in the USP Basin in 2002 (acre-feet)



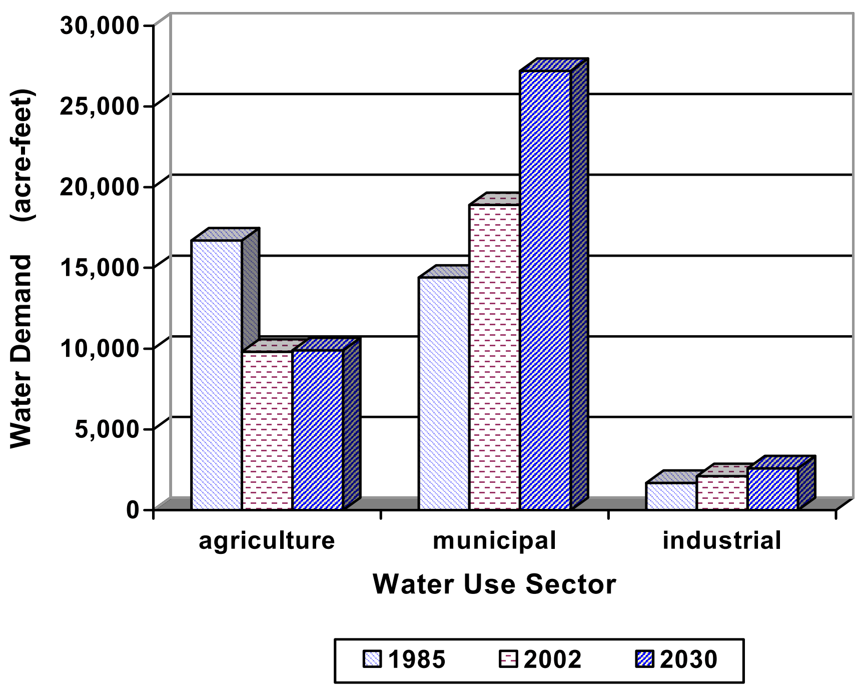
Note: Groundwater refers to water withdrawn from a well or water located within an underground aquifer

A number of water supply alternatives for the Sierra Vista sub-area have been discussed by the community. These include importation of Central Arizona Project Water, groundwater transfers from other basins, inter-basin groundwater transfers, use of mine water, relocation of wells to locations outside of the Basin or to other locations within the Basin, surface water rights acquisitions and associated sever and transfer, and other options. These alternative supplies were not considered in this report because of their speculative nature. Reuse or increase in use of renewable water supplies in lieu of groundwater pumping would benefit the aquifer.

Water demand by water use sector in 1985, 2002 and projected for 2030 is shown in Figure 4-5. The AMA definitions for municipal, industrial and agricultural water use sectors were used, and are explained below in section 4.2. There is a very small demand associated with stock watering supplied by groundwater that is not shown on the graph.

Based on current estimates, in 2002, municipal demand was the largest water use sector in the Basin at 18,800 acre-feet of which 13,700 acre-feet was net use groundwater. Agricultural consumptive use was 9,800 acre-feet and industrial sector use was 2,100 acre-feet of which 2,000 acre-feet was net use groundwater. Since 1985, there has been a significant shift in demand from agricultural water use to municipal water use and this trend is projected to continue as population increases. Total water demand has declined slightly since 1985 primarily due to reductions in agricultural production. However, it is projected that water demand will increase beyond 1985 levels by 2010 as Basin population increases. This situation assumes no further reduction in agricultural use from current levels. Because of the recharge and effluent utilization efforts underway in the Basin, however, it is anticipated that the net use of groundwater will not increase above the 2002 level until after 2010 (see Table 4-2).

Figure 4-5. USP Basin Water Demand by Sector



4.2 Demand Sectors

Under the Groundwater Code, "municipal use" means "…all non-irrigation use of water supplied by a city, town, private water company or irrigation district…" A.R.S. § 45-561. These entities are collectively referred to as "water providers" in this report. For the purposes of this report, municipal use also includes water demand at Fort Huachuca and use by domestic ("exempt") wells. Municipal use includes residential use, non-residential commercial use, and industrial type uses. It also includes irrigated pastures and gardens smaller than two acres in size. Many residents of the Basin obtain water from a domestic well on their property or may share a small production well with their neighbors. Water pumped from domestic wells met about 30% of the municipal demand in 2002.

This report uses the Groundwater Code definition of "industrial use", which is "…a non-irrigation use of water not served by a city, town or private water company." A.R.S. § 45-561. Included are types of industrial users that have specific conservation requirements in the third management plans for the AMAs. In this category are golf courses and parks with more than 10 acres of water-intensive landscaping, sand and gravel facilities, the Apache Nitrogen facility and a dairy. The golf courses and parks served by water providers are included in the municipal sector, the source of the water being the determining factor in how the use is characterized.

Agricultural water use is defined in terms of "irrigation use." In the Groundwater Code, irrigation use means "…the use of groundwater on two or more acres of land to produce plants or parts of plants for sale or human consumption, or for use as feed for livestock, range livestock or poultry." A.R.S. § 45-402. The same definition is used in this report.

Table 4-2 contains detailed information by sector on water demand and supply in the Basin for selected years from 1985 to 2030. This information is described in more detail in the sections following the table. For 2002, the population figures are based on the 2000 Census but adjusted to 2002 using DES estimates. Municipal, agricultural and industrial water use estimates are based on 2002 data. A complete discussion of these sector estimates is found in Appendices G through L.

The groundwater demand total in Table 4-2 has been adjusted to account for the groundwater used by municipal and industrial users that is returned to the aquifer as effluent through artificial and incidental recharge, or net use. The artificial recharge volume is associated with the Fort Huachuca and Sierra Vista effluent recharge facilities. The incidental recharge is from septic tanks and City of Tombstone effluent discharge to Walnut Gulch. Additionally, a small volume of water is incidentally recharged to the aquifer from turf irrigation by municipal and industrial users.

As described below, the agricultural demand and surface water and groundwater supply shown in Table 4-2 is the consumptive use of crops grown since groundwater withdrawal, surface water diversion and irrigation efficiency data are not available.

Table 4-2. USP Basin Water Demand and Supply for Selected Years.

	YEAR					
	1985	1990	2002	2010	2020	2030
AGRICULTURAL						
Irrigated acres	5,300	4,000	3,000	3,000	3,000	3,000
Demand (CU)[1]	**16,700**	**12,700**	**9,800**	**9,900**	**9,900**	**9,900**
Supply (CU)	16,700	12,700	9,800	9,900	9,900	9,900
Surface Water	*2,300*	*2,300*	*2,300*	*2,300*	*2,300*	*2,300*
Effluent	1,100	1,300	0	0	0	0
Groundwater	*13,300*	*9,100*	*7,500*	*7,600*	*7,600*	*7,600*
MUNICIPAL						
Population	60,200	65,300	82,300	91,800	102,400	110,100
Demand	**13,600**	**14,300**	**18,900**	**22,300**	**25,200**	**27,200**
Water Provider	7,600	7,800	11,200	13,600	15,300	16,500
Fort Huachuca	3,300	3,100	1,900	1,900	1,900	1,900
Domestic Well	2,700	3,400	5,700	6,800	8,000	8,800
Supply	13,600	14,300	18,900	22,300	25,200	27,200
Surface Water	240	160	160	160	160	160
Effluent	340	340	810	1,100	1,400	1,600
Groundwater	13,000	13,800	17,900	21,000	23,600	25,400
(Less) Incidental Recharge[2]	*(1,600)*	*(1,700)*	*(2,600)*	*(2,800)*	*(3,100)*	*(3,300)*
(Less) Artificial Recharge[3]	*0*	*0*	*(1,500)*	*(3,900)*	*(4,500)*	*(5,100)*
Groundwater (net use[4])	*11,400*	*12,100*	*13,800*	*14,300*	*16,000*	*17,000*
INDUSTRIAL						
Demand	**1,700**	**1,900**	**2,100**	**2,100**	**2,600**	**2,600**
Supply	*1,700*	*1,900*	*2,100*	*2,100*	*2,600*	*2,600*
Surface Water	0	0	0	0	0	0
Effluent	0	0	0	570	570	570
Groundwater	1,700	1,900	2,100	1,500	2,000	2,000
(Less) Incidental Recharge	*(60)*	*(60)*	*(80)*	*(80)*	*(100)*	*(100)*
Groundwater (net use[4])	*1,600*	*1,800*	*2,000*	*1,400*	*1,900*	*1,900*
OTHER (Stock)						
Demand	**320**	**320**	**320**	**320**	**320**	**320**
Supply Groundwater (net use[4])	*320*	*320*	*320*	*320*	*320*	*320*
TOTAL						
Total Water Demand	**32,300**	**29,200**	**31,100**	**34,600**	**38,000**	**40,000**
Total Groundwater (net use[4])	*26,600*	*23,300*	*23,600*	*23,600*	*25,800*	*26,800*

NOTE: All units are in acre-feet unless otherwise noted. Numbers have been rounded to the nearest hundred or nearest ten. This may result in slight discrepancies in the totals.
[1] Consumptive use is the volume of water used by plants for growth and transpiration.
[2] Incidental recharge is recharge that occurs from septic tanks, turf watering and effluent discharge.
[3] Artificial recharge is recharge of effluent in recharge basins or channels.
[4] Net use is the volume of groundwater pumped and not returned to the aquifer through incidental or artificial recharge.

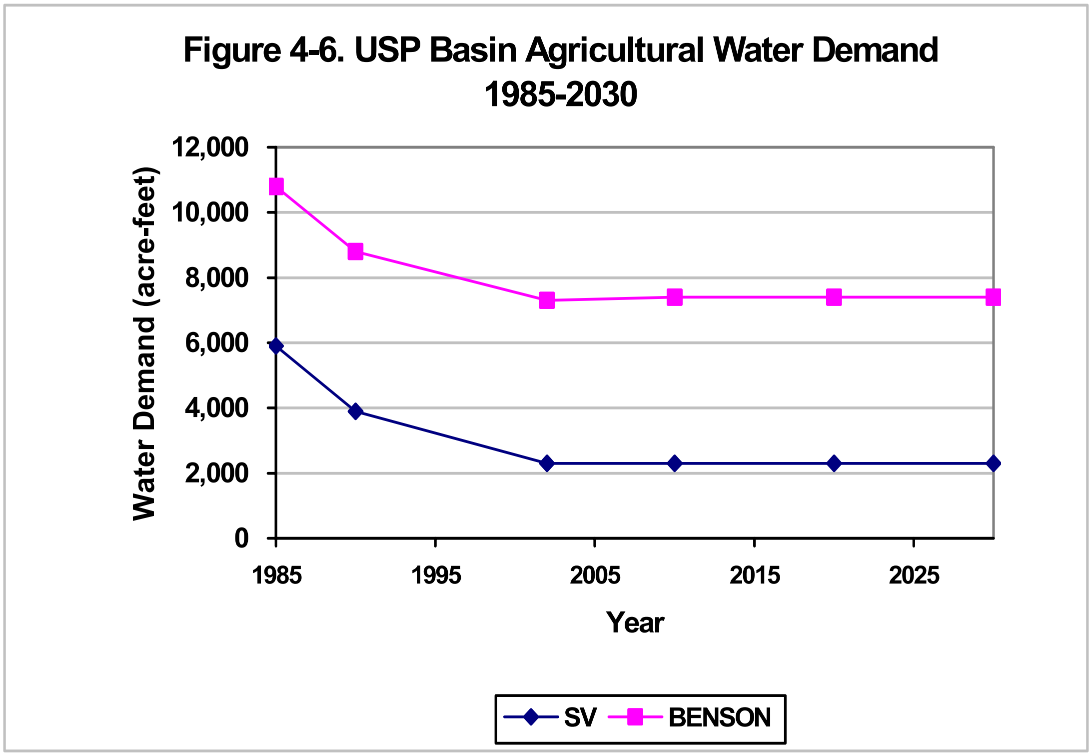
Effluent is used as a municipal supply currently and is expected to increase, and by 2010, plans are to deliver 570 acre-feet of Bisbee effluent to the Turquoise Valley Golf Course, an industrial user, with the remainder recharged to the aquifer. (Sierra Vista Herald, April 30, 2003; Jeff Smith, City of Bisbee, personal commun., January 24, 2003).

4.2.1 Agricultural Demand

Agricultural water demand has declined in the Basin since 1985 and is now present primarily in the Benson and Pomerene areas and in “The Gap” (the Palominas area not included in the San Pedro Riparian National Conservation Area to the north and south). Irrigation is primarily flood irrigation with some sprinkler irrigation, including center pivot irrigation. It is estimated that in 2002, about 77% of the agricultural demand was met by groundwater pumping and 23% by surface water diverted in the Benson sub-area. A small portion of agricultural demand has historically been met with effluent. This demand was associated with the need for disposal of treated wastewater at the Benson and Sierra Vista wastewater treatment plants, and was used to grow pasture. This practice ceased in 2002 with effluent diverted to recharge and turf irrigation. A small volume of effluent has also been surface discharged after lagoon system treatment at the Bisbee-San Jose and Bisbee-Warren wastewater treatment plants.

Figure 4-6 shows the agricultural demand trends in the Benson and Sierra Vista sub-areas from 1985 to 2030. Because pumping data were not available, agricultural demand was estimated by evaluating the number of acres in production and multiplying the number of acres by the consumptive use of the crop grown. This approach does not factor in irrigation efficiency, which varies depending on the irrigation method used. Estimates in the Hydrographic Survey Report for the San Pedro River Watershed (San Pedro HSR) are that a “well maintained” sprinkler irrigation system is approximately 58% efficient while a “well maintained” flood system without tailwater recovery is 45% efficient in the USP Basin. The San Pedro HSR further concluded that sprinkler systems in the San Pedro River watershed lose 4.42% of the irrigation water to evaporation and that flood irrigated systems lose an additional 2% due to conveyance system losses and additional wetted area. Regardless of how much water is applied to a crop, water used in excess of the consumptive use of the crop and the evaporative and conveyance losses returns to the aquifer. Because it was not possible to conduct a complete inventory of the current irrigation method used on the almost 3,000 acres in production, and, because other than consumptive use, all but a relatively small percentage of water returns to the aquifer of the total volume pumped, the consumptive use volume is a reasonable estimation of the total unrecoverable losses to the groundwater or surface water system. This method makes no assumptions of irrigation efficiency.

The amount of agricultural acreage was estimated using information in the San Pedro HSR, analysis of satellite imagery from 1984, 1990, 1997 and 2001, and from a May 2002 field survey in the Benson sub-area. In addition, potentially irrigated land in the Sierra Vista sub-area, particularly in “The Gap” area, was field investigated in January and July 2003 to verify photo and satellite analysis. Because deficit irrigated acres are not discernible from satellite imagery analysis, deficit irrigated acreage was estimated based on several sources. For 1985, and 1990, the proportion of deficit irrigated acres to non-deficit irrigated acres from the San Pedro HSR was used. For 2002, deficit irrigated



acreage in the Sierra Vista sub-area was estimated from field surveys, aerial photo analysis and review of the San Pedro HSR For the Benson sub-area, since not all acreage was accessible, the field data were cross- referenced to satellite imagery and the deficit irrigated acres were estimated using the proportion of deficit irrigated acres to non-deficit irrigated acres in the San Pedro HSR. The consumptive use rate is that used for the Santa Cruz AMA, which has a similar climate to that in the Basin. Crop type was estimated from data in the San Pedro HSR and from the field surveys. The predominant crop is pasture in both sub-areas. In addition, about 120 acres of pecan and other trees are irrigated in the Benson sub-area. In the Sierra Vista sub-area there are about 20 acres of irrigated grapes. Projections assume current acreage. A summary of deficit and non-deficit acreage and consumptive use estimates are found in Table 4-3 and a complete discussion of the agricultural assumptions is found in Appendix G.

Table 4-3. Summary of Agricultural Acreage and Consumptive Use Estimates for the Benson and Sierra Vista Sub-areas, 2002.

	Benson Sub-area	**Sierra Vista Sub-area**
Total Acres	2,200 acres	800 acres
Non-deficit irrigated acres	1,910 acres	520 acres
Consumptive use - pasture	3.43 AFA	3.43 AFA (500 acres)
Consumptive use – vineyards	N/A	3.0 AFA (20 acres)
Total non-deficit acres consumptive use	6,550 AF	1780 AF
Deficit irrigated acres	240 acres	280 acres
Consumptive use – crop mix	2.95 AFA	2.61 AFA
Total deficit-irrigated acres consumptive use	710 AF	730 AF
Total Consumptive Use	**7,300 AF**	**2,500 AF**

Note: Numbers rounded to the nearest hundred or nearest ten.
AFA = acre-feet/acre; AF = acre-feet

Benson Sub-area

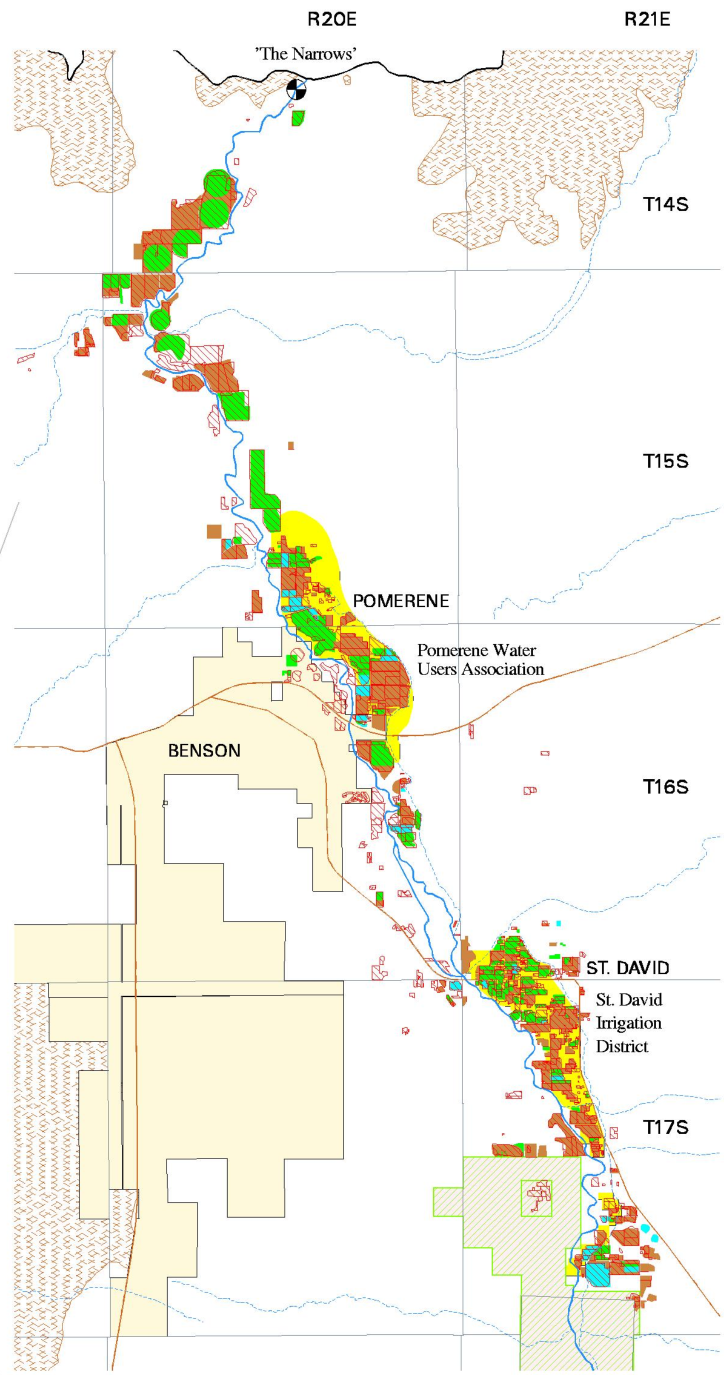
ADWR conducted a field survey in May 2002 that revisited lands investigated for the San Pedro HSR (Figure 4-7). There are two irrigation providers in the Benson sub-area that deliver surface water: the Saint David Irrigation District (SDID) and the Pomerene Water Users Association (PWUA). The Department determined that approximately 39% of the currently irrigated agricultural lands in the Benson sub-area are served by either PWUA or SDID. Approximately 400 acres in each district were actively irrigated in 2002. ADWR estimates that in 2002 surface water represented about 31% of the agricultural supply; actual diversion and use data are unavailable. The field survey also found an additional 1,300 acres of non-district farmland irrigated with groundwater, and identified approximately 400 acres as “fallow”, *i.e.* not currently irrigated but in an irrigation-ready condition. The fallow acreage is not included in the agricultural demand estimates. Although ADWR assumed that this amount of land is fallow year to year, it does represent an additional potential consumptive use by agriculture of about 1,350 acre-feet per year. The field survey data was supplemented with satellite imagery analysis because not all fields were accessible. See Appendix D for details of the field survey.

SDID is served by a 9-mile long ditch and by two wells. The wells are used when there is insufficient water to divert from the San Pedro River. Generally, surface flow is available during the winter or early spring but varies considerably year-to-year depending on climatic conditions. The diversion point is an earthen dam constructed in the river channel that is routinely washed away during high flow events. The dam and about one and a half miles of the ditch are located on Bureau of Land Management (BLM) land within the northernmost part of the San Pedro Riparian National Conservation Area (SPRNCA). A 50-year permit agreement with the BLM allows the district to reconstruct the dam when it is washed out and to perform maintenance.

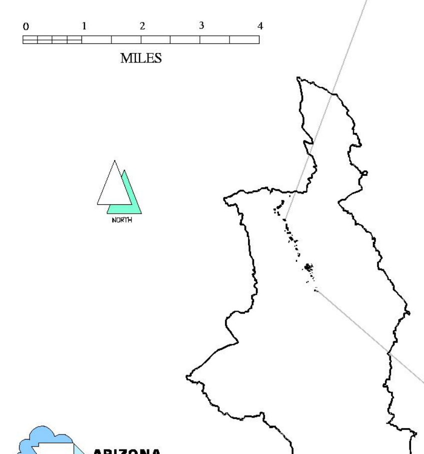
Figure 4 –7

Upper San Pedro Basin

Agricultural Lands in the Benson Sub–Area



Cities and Towns
USGS Stream Gages on the San Pedro River
Major Roads
Townships & Ranges
San Pedro River
Tributary Streams to the San Pedro River
Upper San Pedro Basin Boundary
Hardrock
San Pedro National Riparian Conservation Area
City Boundaries
Irrigation Districts
1991 HSR Investigated Agriculture (6,552 Ac) (Not all investigated acreage was active agriculture)
2002 Irrigation –Active Fields (2,151 Ac)
2002 Fallow –Crop-ready Fields (420 Ac)
2002 No Irrigation –Unmaintained Fields & Irrigation Works (3,135 Ac)



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March, 2005

The PWUA diverts water from the San Pedro River via a diversion dam located about three fourths of a mile north of the State Route 80 highway bridge at St. David. The Pomerene Canal is about seven miles long and delivers water to agricultural lands primarily in the vicinity of Pomerene, northeast of Benson. Surface water is typically only available for use during the period from November to May, and PWUA does not operate any groundwater wells to supplement the supply. However, there are members who use the canal system to deliver their own pumped water to their fields. No records or measurements of water deliveries were available to ADWR. (see Chapter 3 for additional information on water diversions for irrigation.)

Historically, the Benson sub-area has had a significant agricultural water demand sector with about 3,200 acres in irrigation in 1985. Since that time approximately one-third has gone out of production. It is possible that additional agricultural lands in the Benson sub-area will go out of production in the future; however, in recent years, while there are annual fluctuations in the number of acres irrigated, the amount appears to have stabilized around 2,200 acres. Because of the uncertainty in the rate of agricultural land retirement and to avoid underestimating future demand, agricultural demand has been projected to remain constant with the exception of a planned 40-acre vineyard associated with the Bachmann Springs development northeast of Tombstone.

Sierra Vista Sub-area

ADWR staff visited potentially irrigated lands in the Sierra Vista sub-area in 2003 to field verify their status (Figure 4-8). Using a combination of field investigation, San Pedro HSR information and aerial photos, staff was able to confirm initial estimates of irrigated acres. No surface water diversions for agricultural use were found, although some limited amount of surface water may be diverted at some locations. There were four center pivot sprinkler systems irrigating approximately 500 acres and smaller flood irrigated acreage amounting to a total of about 800 irrigated acres. A complete discussion of the field investigation is found in Appendix H.

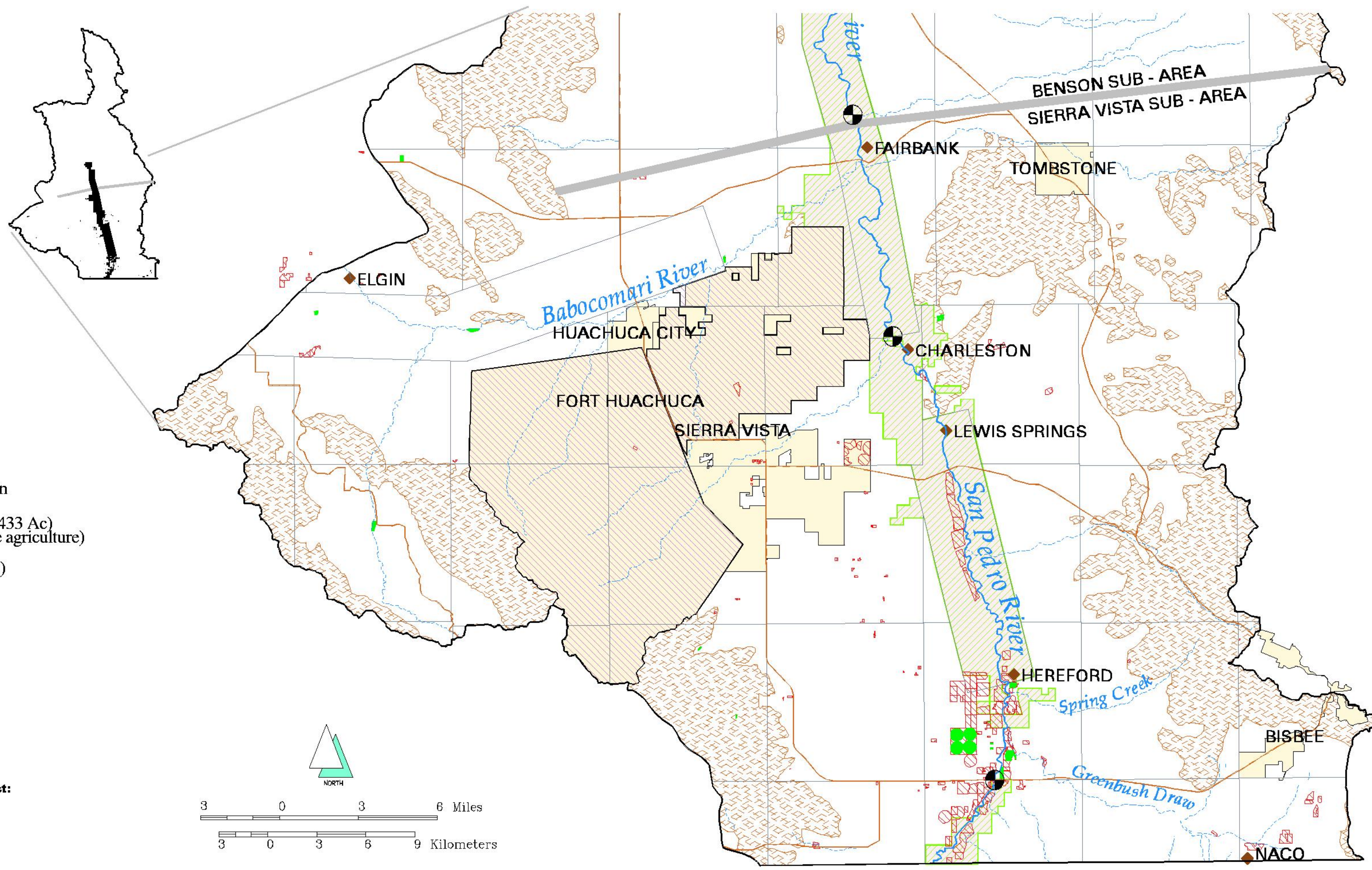
Up until 2002, approximately 300 acres of pasture was irrigated with effluent from the Sierra Vista Wastewater Treatment Plant. This acreage has been taken out of production as the effluent is now diverted for groundwater recharge purposes. Wastewater from the Warren and San Jose treatment plants that serve part of Bisbee is discharged to a series of lagoons and the residual is applied to pasture. The volume applied is small, approximately 150 acre-feet/year and irrigation is not discernible from satellite imagery analysis. It was not included in the agricultural demand.

Prior to 1980, more than 6,600 acres were estimated to be in production according to the San Pedro HSR. With the establishment of the SPRNCA almost 2,000 acres were retired from production. It is anticipated that there will be a further reduction in agricultural use due to several factors. The BLM, Nature Conservancy, U.S. Fish and Wildlife Service (USFWS) and Fort Huachuca are working together to establish conservation easements to reduce irrigation and other pumpage near the San Pedro River. In addition, it is likely that some agricultural land will continue to be purchased and subdivided in the future.

Figure 4 –8

Upper San Pedro Basin

Agricultural Lands in the Sierra Vista Sub–Area



- Cities and Towns
- USGS Stream Gages on the San Pedro River
- Major Roads
- Townships & Ranges
- San Pedro River
- Tributary Streams to the San Pedro River
- Upper San Pedro Basin Boundary
- Subbasin Boundary
- Hardrock
- Fort Huachuca Military Reservation
- San Pedro National Riparian Conservation Area
- City Boundaries
- Sub –Area Boundary (Informal division created for discussion purposes)
- 1991 HSR Investigated Agriculture (6,433 Ac) (Not all investigated acreage was active agriculture)
- 2002 Irrigation –Active Fields (803 Ac)

ARIZONA DEPARTMENT OF WATER RESOURCES

For more information about this map contact:

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March, 2005

Nonetheless, because of uncertainties in prediction, lack of current restrictions on new irrigation, and to avoid underestimating demand, ADWR projected agricultural acres at current levels. It should be noted that although the community of Elgin is within the Basin, most of the vineyards in the Elgin area are just outside of the Basin boundaries and are not included in this report.

4.2.2 Municipal Demand

Municipal demand is linked to population. This report uses data from the 2000 United States Census, DES estimates for 2002 and DES projections from 1997 which are the most recent available. The methodology to determine populations for the Basin, for each sub-area and for unincorporated areas are discussed in Appendix I.

Benson sub-area projections were adjusted to include developments that have been approved, and demand assumptions in the City of Benson Designation of Adequate Water Supply (DAWS) Modification application (Application No. 21-400351). This adjustment includes only "The Canyons" at Whetstone Ranch with 1,150 units. Phase I (300 units) was approved in 2002. (Mark Holt, City of Benson, personal commun., September, 2002). The entire Whetstone Ranch property stretches south of Benson along State Route 90 to just north of Kartchner Caverns State Park. As submitted in the DAWS Modification application, the development plans include more than 18,000 housing units and eight golf courses with an associated demand at build out of 9,465 acre-feet per year. The current City of Benson designation is for 5,905 acre-feet per year.

Benson sub-area demand projections were also adjusted to include the Bachmann Springs development northeast of Tombstone. Approved by Cochise County, with construction anticipated to begin in 2005, it is planned for 1,135 units, a resort hotel, 18-hole golf course, shops and conference facilities. This is a resort community of luxury second homes with no permanent residents assumed. An estimated municipal water demand of 1,100 acre-feet/year, of which 180 acre-feet is effluent, is included in the projections.

Smith Ranch, consisting of approximately 5,000 homes planned west of Benson, is in the early stages of County review and therefore is not included in the projections for this report. An Analysis of Water Adequacy application was filed in February 2005.

By 2030, population projections for the Benson sub-area show an increase of about 6,000 additional residents. In the Sierra Vista sub-area, the population is expected to increase by almost 22,000. Incorporated area and county projections are available from DES. For the unincorporated area, it was assumed that the proportions of that population served by private water companies and by exempt wells would remain constant in the future.

Water demand information was available from several sources. A primary source was the Arizona Corporation Commission (ACC), which regulates private water company rates and requires annual reporting of the volume of water pumped and sold to customers. In some cases water providers only report water sales, which do not reflect water pumpage. Invariably, water is lost between the wellhead and the point of delivery. This “lost water” is due to actual leaks in the system, under-recording delivery meters, construction water taken at hydrants that is not metered, and even to illegal interconnects or other water theft. In order to calculate a groundwater pumpage estimate it is necessary to adjust delivery information to include system water losses. If pumpage information was not available, an assumption of 10% losses was used for providers that would be classified as large if within an AMA (pumping more than 250 acre-feet/year) and 15% for smaller providers. These percentages are the regulatory standards for lost and unaccounted for water in the AMAs.

Other information on municipal water demand came from direct communication with water providers and from estimates of water demand for domestic wells. The demand associated with exempt wells is not metered or reported to any entity. This demand was estimated based on large lot parcel use in the Tucson AMA for which a long history of metered water use is available, with an additional demand associated with irrigated lands of less than two acres in size based on information in the San Pedro HSR. Because proportionately more small, irrigated lands exist in the Benson sub-area, the acreage per person demand estimate differs between sub-areas. The estimated demand in the Sierra Vista sub-area is therefore .35 acre-feet/person and .55 acre-feet/person in the Benson sub-area. The pumpage for Fort Huachuca comes from the Fort Huachuca Biological Opinion Annual Report for 2002. Information on municipal water demand assumptions is found in Appendix J.

There are 30 water systems that serve municipal users in the Basin. Only three systems are public: City of Benson, City of Tombstone and Huachuca City. Fort Huachuca is served from wells at the facility. The remaining systems are private water companies regulated by the ACC. Three “large” private water companies serve customers within the Sierra Vista City limits. Detailed information on water system demand is found in Appendix K. Water demand by the eight largest systems is shown in Table 4-4. These eight systems serve 250 acre-feet or more per year and would be categorized as large providers in an AMA. These systems account for 96% of the total water system demand in the Basin but only 57% of the total municipal demand. All but the City of Benson system are located in the Sierra Vista sub-area.

Based on the number of connections and the 2000 Census person per housing unit figure, it is estimated that gallon per capita per day (GPCD) rates range from approximately 124 to 196 GPCD for the large providers. The GPCD rate for the entire Basin is about 205 GPCD, which includes exempt well use and related irrigation of less than two acres, golf courses and parks served by water companies (including effluent irrigation), residential and commercial use, and Fort Huachuca water use.

There are municipal water conservation programs in the Basin as discussed in more detail in Chapter 6, and a number of additional conservation programs are planned by local entities. These programs may result in reductions in per capita water use in the Basin. There are, however, many variables that affect estimates of savings from water conservation programs. These include the ability to measure program effectiveness, the impact of weather, the difficulty of modifying behavior and the need for ongoing efforts to ensure that initial savings are maintained. For this study, reductions in per capita use were not assumed in the projections.

Table 4-4. 2002 Large Provider (>250 acre-feet/year) Water Demand in the USP Basin.

Water Provider	Actual/Estimated Water Demand (acre-feet)
Arizona W.C. – Bisbee	1,222
Arizona W.C. – Sierra Vista*	1,299
Bella Vista Water Company*	3,640
Benson, City of	813
East Slope Water Company	306
Fort Huachuca	1,947
Huachuca City	250
Pueblo del Sol Water Co.*	1,355
Total	**10,832**

* Water providers within the Sierra Vista city limits.

Within existing AMAs, some water provider customers are defined as “individual users” because of their relatively large volume of water use. They are generally regulated under the same conservation requirements as industrial users, but because of the source of their water supply, the demand is considered a municipal demand. Table 4-5 shows identified individual users in the USP Basin. Water use at the San Pedro Golf Course is estimated. Two of these individual users are supplied by Fort Huachuca, a federal facility. Typically, federal facilities voluntarily comply with conservation requirements within existing AMAs. Pueblo del Sol Golf Course receives about 5% of its annual water supply from Pueblo del Sol Water Company and is listed as an industrial user (Richard Darling, PDS Water Company, personal commun., January, 2003). About 73% of the individual user demand was met by effluent in 2002.

Table 4-5. 2002 Individual Users and Water Demand in the USP Basin

Facility	Provider	Water Demand (acre-feet/year)
Chaffee Parade Field *	Fort Huachuca	53 (reported)
Mountain View Golf Course *	Fort Huachuca	371 (reported)
San Pedro Golf Course – Benson*	City of Benson	500 (estimate)
Veterans Park	City of Sierra Vista	179 (reported)
Total		**1103**

Note: * Facilites use effluent

Most of the water supply for municipal demand is groundwater. A small amount of surface water is used by the City of Tombstone. The City of Tombstone began using surface water from springs located in the Huachuca Mountains in 1881, and currently diverts water from Miller and Carr Springs. This water is conveyed through an 80,000 foot, gravity fed, seven-inch diameter steel pipeline. The theoretical maximum capacity of the Tombstone aqueduct is about 1,000 acre-feet. However, this supply is not metered at its delivery point, and it is estimated that only about 160 acre-feet actually goes into the Tombstone water system (Putman and others, 1988**;** ADWR, Hydrographic Survey Report for the San Pedro River Watershed, WFR #111-21-32, 1991b).

Effluent is used to meet some municipal demand. In the Benson sub-area, beginning in 2002, effluent is diverted to serve the new San Pedro Golf Course (Mark Holt, City of Benson, personal commun., September, 2002). In 2002, 380 acre-feet of effluent was delivered to the course (Benson City staff, written commun., 2004). Effluent is also used at Fort Huachuca for turf irrigation as well as for recharge.

The plans to consolidate the three municipal treatment plants that serve the Bisbee population centers of Old Bisbee, Warren and San Jose into a single plant at San Jose will provide an opportunity for effluent reuse. Plans are to deliver treated effluent to irrigate the Turquoise Valley Golf Course at Naco (an industrial facility) and to recharge any additional effluent. In addition, the collection system will be improved to reduce leakage and a substantial number of residents on septic systems will be connected to the sewer system. Currently, effluent from Old Bisbee (about 130,000 gpd) is discharged to Mule Gulch in the Douglas Basin.

4.2.3 Industrial Demand

As mentioned previously, for the purposes of this report, industrial water demand is an industrial type use served by its own well, not by a water provider. Categories of industrial water users with specific regulatory requirements are defined in management plans for AMAs. These requirements are discussed in more detail in Chapter 6.

Industrial water demand in the Basin consists of an estimated five sand and gravel facilities, one dairy, an ammonium nitrate manufacturing plant, and three golf courses**.** ADWR identified golf courses and other turf-related facilities (ten or more acres of water-intensive landscaping) through reports, interviews and satellite imagery. Water demand was estimated for most of these facilities, although data was reported to ADWR for Apache Nitrogen (Table 4-6). Industrial sector projections assume that existing uses remain constant, and that one new “industrial” golf course is constructed in the Sierra Vista sub-area by 2020. All current water supplies are groundwater and all new demand is also projected to be groundwater. As mentioned above, effluent is assumed to replace groundwater use at the Turquoise Valley Golf Course beginning in 2010. This volume is estimated at 570 acre-feet/year. Detailed information on industrial water demand assumptions is found in Appendix L.

Table 4-6. 2002 Industrial Users and Water Demand in the USP Basin.

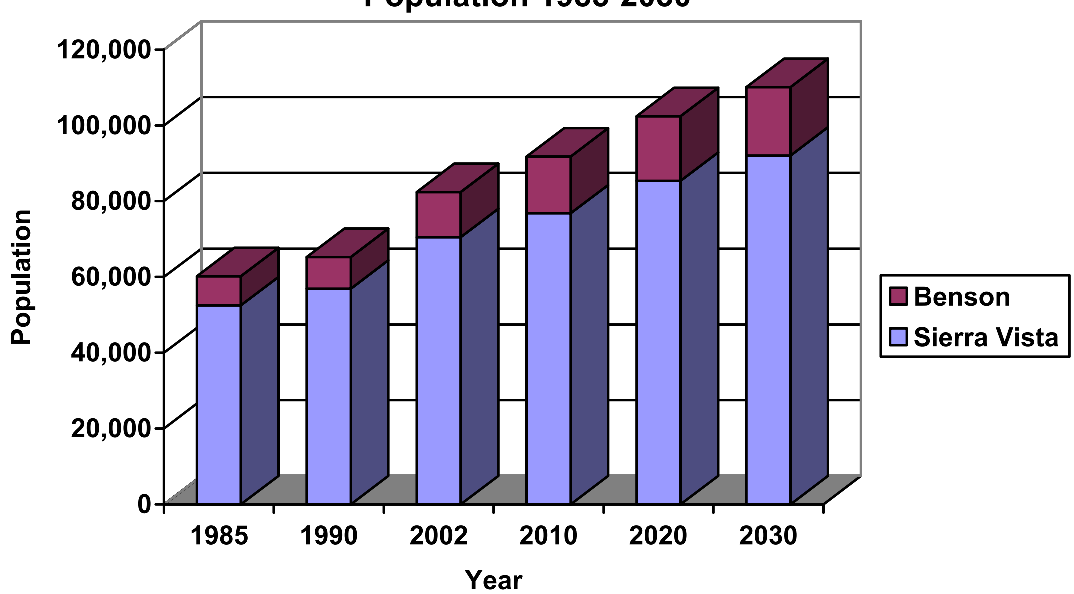
Facility	Water Demand (acre-feet/year)
Turquoise Hills G.C. (Benson)	500 (estimate)
Turquoise Valley G.C. (Naco)	577 (reported)
Pueblo del Sol G.C.*	475 (estimate)
Dairy (Pomerene Area)	41 (estimate)
Sand and Gravel (5)	211 (estimate)
Apache Nitrogen Products**	288 (reported)
Total	**2,092**

Note: * 5% of demand served by Pueblo del Sol W.C.
** 2001 data

4.3 Sierra Vista and Benson Sub-area Demand and Supply Comparison

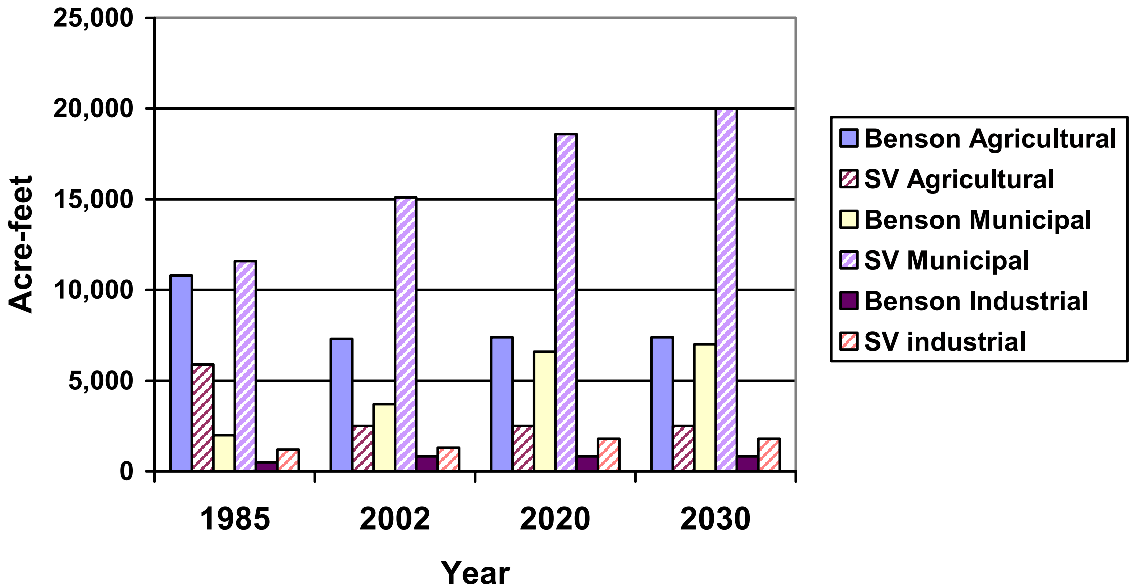
The Sierra Vista and Benson sub-areas are substantially different in type of water demand, land use and population. In 2002, the Sierra Vista sub-area had more than four times the municipal demand and almost six times the population of the Benson sub-area. Between 1990 and 2002 the population in the Sierra Vista sub-area grew by 2.2% per year and grew by 3.5% per year in the Benson sub-area (and by 2.3% for the entire Basin including all of Bisbee). Population growth is shown in Figure 4-9. As mentioned previously, the master planned Whetstone Ranch development and proposed Smith Ranch development in the Benson sub-area would result in a substantial increase in the population and water demand of the northern part of the Basin if development proceeds as planned.

Figure 4-9 . Benson and Sierra Vista Sub-area Population 1985-2030



In the Sierra Vista sub-area, 79% of the total demand in 2002 was municipal compared to 30% in the Benson sub-area. In both sub-areas, the municipal sector is the fastest growing sector by far. Agricultural use, though it has declined since 1985, still makes up 61% of the Benson sub-area demand and, assuming current acreage stays in production, will still be the largest water demand sector in 2030. Industrial use in both sub-areas is expected to remain small. These relationships are shown graphically in Figure 4-10.

Figure 4-10. Benson and Sierra Vista Sub-area Sector Water Demand 1985-2030



Groundwater is the predominant supply of water in both sub-areas, particularly in the Sierra Vista sub-area as shown in Figures 4-11 and 4-12 and is projected to remain so in the future due to limited alternative water supplies.

Effluent is a small percentage of the water supply in both sub-areas. However, both sub-areas utilize much of the effluent produced either for golf course/turf irrigation or for groundwater recharge. Surface water diverted from the San Pedro River for irrigation is estimated to meet about 19 percent of the total water demand of the Benson sub-area compared to the very small municipal surface water demand in the Sierra Vista sub-area.

Figure 4-11. 2002 Sierra Vista Sub-area Water Demand

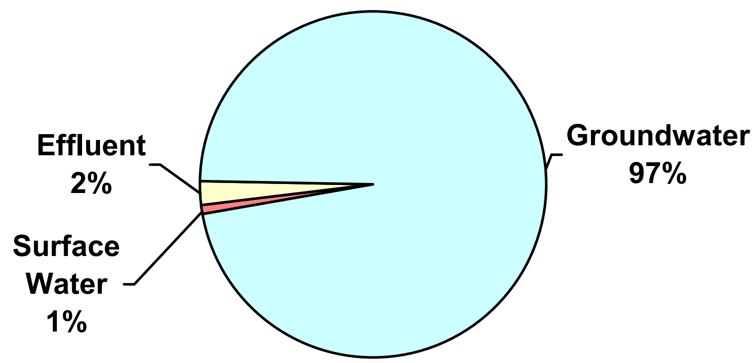
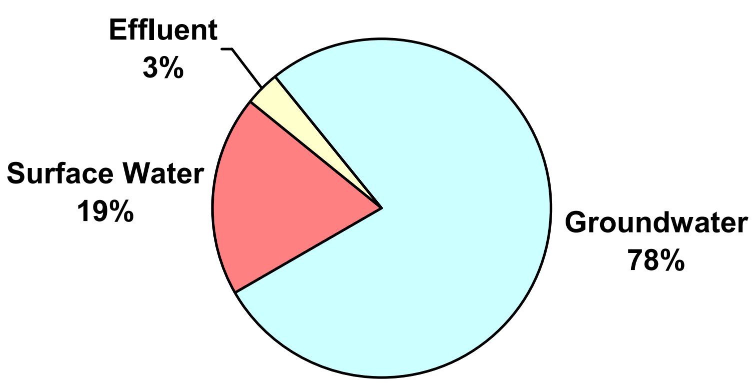


Figure 4-12. 2002 Benson Sub-area Water Demand



Note: Groundwater refers to water withdrawn from a well or water located within an underground aquifer

The water supply and demand information provided in Table 4-2 for the entire Basin has been separated by sub-area in Table 4-7. Of the 19,100 acre-feet of water demand in the Sierra Vista sub-area in 2002, approximately 14,900 acre-feet was net use groundwater. Approximately 420 acre-feet of effluent and 160 acre-feet of surface water were used directly in the Sierra Vista sub-area. In addition to the 1,500 acre-feet of effluent recharge that returns to the aquifer after use, it is estimated that 2,050 acre-feet is incidentally recharged.

In the Benson sub-area the total water demand in 2002 was 12,000 acre-feet of which 8,700 acre-feet was net use groundwater. Approximately 2,300 acre-feet of surface water and 380 acre-feet of effluent was used. It is estimated that about 620 acre-feet was incidentally recharged to the aquifer in 2002.

The assumptions discussed previously result in a total future water demand distribution between the sub-areas similar to that found currently. The percentage of net use groundwater to the total water demand is anticipated to decline in the Sierra Vista sub-area due primarily to increasing volumes of artificial recharge while remaining about the same in the Benson sub-area.

The volume of effluent used for turf irrigation in the Benson sub-area is expected to surpass that used in the Sierra Vista sub-area by 2020, and by 2030, and it is projected that utilization will increase to about 900 acre-feet in the Sierra Vista sub-area and 1,200 acre-feet in the Benson sub-area.

All the current effluent recharge in the Basin, approximately 1,500 acre-feet, occurs in the Sierra Vista sub-area and is projected to increase to 5,100 acre-feet by 2030. At this time, there are no known plans to artificially recharge effluent in the Benson sub-area. Surface water represents a significant agricultural irrigation supply in the Benson sub-area and will likely remain so in the future assuming current conditions.

Table 4-7. Sierra Vista and Benson Sub-area Demand and Supply.

SECTOR	1985		1990		2002		2010		2020		2030	
	SV	BEN	SV	BEN	SV	BEN	SV	BEN	SV	BEN	SV	BEN
AGRICULTURAL												
Irrigated acres	2,000	3,200	1,400	2,600	800	2,200	800	2,200	800	2,200	800	2,200
Demand (CU[1])	**5,900**	**10,800**	**3,900**	**8,800**	**2,500**	**7,300**	**2,500**	**7,400**	**2,500**	**7,400**	**2,500**	**7,400**
Supply (CU)	5,900	10,800	3,900	8,800	2,500	7,300	2,500	7,400	2,500	7,400	2,500	7,400
Surface Water	0	2,300	0	2,300	0	2,300	0	2,300	0	2,300	0	2,300
Effluent	870	240	1,100	180	0	0	0	0	0	0	0	0
Groundwater	*5,000*	*8,300*	*2,800*	*6,300*	*2,500*	*5,000*	*2,500*	*5,100*	*2,500*	*5,100*	*2,500*	*5,100*
MUNICIPAL												
Population	52,200	8,000	56,600	8,700	70,100	12,200	76,500	15,300	85,100	17,300	91,700	18,400
Demand	**11,600**	**2,000**	**12,100**	**2,200**	**15,100**	**3,700**	**16,600**	**5,700**	**18,600**	**6,600**	**20,000**	**7,100**
Water Provider	6,600	1,000	6,700	1,000	9,300	2,000	10,100	3,500	11,300	4,000	12,100	4,400
Fort Huachuca	3,300		3,100		1,900		1,900		1,900		1,900	
Domestic Well	1,700	1,000	2,300	1,200	3,900	1,800	4,500	2,300	5,400	2,600	6,000	2,700
Supply	11,600	2,000	12,100	2,200	15,100	3,700	16,600	5,700	18,600	6,600	20,000	7,100
Surface Water	240	0	160	0	160	0	160	0	160	0	160	0
Effluent	340	0	340	0	420	380	370	700	370	1,000	370	1,200
Groundwater	11,000	2,000	11,600	2,200	14,500	3,300	16,100	5,000	18,100	5,600	19,500	5,900
(Less) Incidental Recharge[2]	*(1,300)*	*(270)*	*(1,400)*	*(310)*	*(2,000)*	*(590)*	*(2,100)*	*(680)*	*(2,300)*	*(790)*	*(2,500)*	*(840)*
(Less) Artificial Recharge[3]	*0*	*0*	*0*	*0*	*(1,500)*	*0*	*(3,900)*	*0*	*(4,500)*	*0*	*(5,100)*	*0*
Groundwater (net use)[4]	*9,700*	*1,700*	*10,200*	*1,900*	*11,000*	*2,700*	*10,100*	*4,300*	*11,300*	*4,800*	*11,900*	*5,100*
INDUSTRIAL												
Demand	**1,200**	**500**	**1,200**	**710**	**1,300**	**830**	**1,300**	**830**	**1,800**	**830**	**1,800**	**830**
Supply	1,200	500	1,200	710	1,300	830	1,300	830	1,800	830	1,800	830
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0
Effluent	0	0	0	0	0	0	570	0	570	0	570	0
Groundwater	1,200	500	1,200	710	1,300	830	700	830	1,200	830	1,200	830
(Less) Incidental Recharge	*(50)*	*(10)*	*(50)*	*(10)*	*(50)*	*(30)*	*(50)*	*(30)*	*(80)*	*(30)*	*(80)*	*(30)*
Groundwater (net use)[4]	*1,200*	*490*	*1,200*	*700*	*1,300*	*800*	*650*	*800*	*1,100*	*800*	*1,100*	*800*
OTHER (Stock)												
Demand	**160**	**160**	**160**	**160**	**160**	**160**	**160**	**160**	**160**	**160**	**160**	**160**
Supply: GW (net use)[4]	*160*	*160*	*160*	*160*	*160*	*160*	*160*	*160*	*160*	*160*	*160*	*160*
TOTAL												
Total Water Demand	**18,800**	**13,500**	**17,400**	**11,800**	**19,100**	**12,000**	**20,500**	**14,100**	**23,000**	**15,000**	**24,500**	**15,500**
Total GW (net use)[4]	*15,900*	*10,700*	*14,200*	*9,100*	*14,900*	*8,700*	*13,300*	*10,400*	*15,000*	*10,900*	*15,700*	*11,200*

NOTE: all units are in acre-feet unless otherwise noted. Numbers have been rounded to the nearest hundred or ten. This may result in slight discrepancies in the totals.

[1] Consumptive use is the volume of water used by plants for growth and transpiration.

[2] Incidental recharge is recharge that occurs from septic tanks, turf watering and effluent discharge. [3] Artificial recharge is recharge of effluent in recharge basins or channels.

[4] Net use is the volume of groundwater (GW) pumped and not returned to the aquifer through artificial or incidental recharge.

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CHAPTER 5

ANALYSIS OF PREDICTIVE STUDIES

The Department's recent findings regarding the USP Basin hydrology and cultural water demands, discussed in Chapters 3 and 4, provide an opportunity to compare these findings to those in past predictive studies of the Basin. This Chapter discusses several recent studies of the USP Basin, and the Department's previous evaluation of the Basin for AMA designation in 1988. These studies have attempted to forecast the impacts of various water use scenarios on the regional hydrologic system. This Chapter includes the Department's findings based on recently measured data and analyses of recent studies in the Basin.

5.1 Past Predictive Studies of the USP Basin

ADWR previously reviewed the Basin for potential AMA designation in 1988 and found that conditions at that time did not exist for AMA designation. As part of that study, Putman and others (1988) used a USGS groundwater model (Freethey, 1982) to estimate the effect of groundwater pumping on groundwater depletions. The model covered a portion of the USP Basin from the U.S.- Mexico border to Fairbank.

Putman and others (1988) made the following conclusions. Pumpage in the Sierra Vista sub-area had not affected that portion of the regional aquifer adjacent to the San Pedro River except near Hereford. This pumping was related to agricultural uses. Around the Sierra Vista area, groundwater modeling results indicated that continued groundwater pumpage between 1986 and the year 2000 would mine an additional 208,000 acre-feet of groundwater from the regional aquifer, resulting in a maximum groundwater decline of about 80 feet, at a maximum rate of about 6 feet per year. The updated model used to project water levels in the year 2000 showed that water levels in the regional aquifer several miles west of the San Pedro River would rise up to 20 feet at Hereford, would decline by about 10 feet west of Lewis Springs, and would decline by about 10 feet west of Charleston.

Additional findings by Putman and others (1988) stated that the artesian head present in some portions of the regional aquifer underlying the floodplain alluvium of the San Pedro River had decreased somewhat over time due to groundwater development in these areas. The extent of the decrease was difficult to quantify due to the lack of data. This conclusion was based on a comparison of descriptive reports on artesian conditions in very early hydrologic reports on the USP Basin with later hydrologic reports on the area. The shallow floodplain aquifer, which underlies the San Pedro River, showed no long-term declines in water level. Putman and others (1988) predicted that the retirement of agricultural lands acquired by the U.S. Bureau of Land Management (BLM) in the San Pedro Riparian National Conservation Area (SPRNCA) would allow water levels in both the confined and unconfined regional aquifer to rise, enhancing groundwater discharge rates to the floodplain alluvium.

The 1988 report by Putman and others also concluded that no land subsidence had occurred in the USP Basin (Strange, 1984) and that groundwater use was found not to be affecting water quality. There were no known regional water quality problems in the USP Basin noted, although there were several local problems due to industrial and sewage treatment plant sources.

The next regional evaluation of the Sierra Vista sub-area was conducted by Vionnet and Maddock (1992). They developed a model of the Basin that incorporated a refined modeling package to better simulate phreatophyte water use. This model was also based on Freethey (1982) and incorporated pumpage data from the Putman and others (1988) report. The evapotranspiration package used to model riparian water use had to be adjusted to a use rate of about half of the conceptual estimates. This is in line with more recent studies that indicate that the riparian community receives substantial supplies of water from rainfall events and bank storage after flood events, and is not entirely dependent on a deep root system for water (Corell and others, 1996; Chehbouni and others, 2000; Snyder and Williams, 2000).

Eight years after the 1988 Putman and others report, the Department (Corell and others, 1996) developed a new groundwater model that covered most of the Sierra Vista sub-area. This model incorporated new information regarding conservation efforts by Fort Huachuca and Sierra Vista, as well as the retirement of agricultural lands due to the establishment of the SPRNCA by the BLM in 1988. The new model was used to project Basin conditions between the years 1990 and 2030 (Corell, 1996).

Corell studied five alternative development scenarios at the request of the Upper San Pedro Technical Committee and the Cochise County Board of Supervisors (Corell, 1996). Scenarios were sketched out at the direction of the Technical Committee, which served as advisor to the Cochise County Board of Supervisors. These alternatives ranged from relatively low growth and low water use to relatively high growth and high water use. They also incorporated the retirement of agricultural lands south of Fairbank in several scenarios and the presence of recharge projects operated by Sierra Vista and Fort Huachuca in others. Corell ran the future water use scenarios for the period 1990-2030. Full results are presented in Corell (1996).

The simulated groundwater-level changes shown in the results of the Department's 1996 model projections reflect an interplay between factors that increase or decrease water demand. Removing agricultural land from the southern part of the Basin decreased groundwater withdrawals close to the San Pedro River, allowing groundwater levels to stabilize or rise. Construction of recharge projects by Sierra Vista and Fort Huachuca caused groundwater levels to rise near the projects and mitigated the cone of depression under Sierra Vista and Fort Huachuca. The recharge projects also caused groundwater levels between the project locations and the river to rise. These effects were offset by increasing demand from riparian growth within SPRNCA and from population growth in the model area. The rising groundwater levels simulated by some of the alternative scenarios were phenomena that lasted for several decades before declining due to increasing demand by municipal water users, including rural residents.

The Commission for Environmental Cooperation (CEC) examined the USP Basin in 1999 to determine strategies for preserving riparian habitat for migratory bird use. The CEC examined various tools available for hydrologic analysis and chose to use the Department's 1996 model of the Sierra Vista sub-area (Corell and others, 1996) to analyze several alternative water use scenarios. Their results were similar to Corell (1996). Many of the alternatives have institutional, legal, or economic constraints, but the range of solutions examined provides a good overview of alternative Basin management strategies.

Goode and Maddock (2000) also estimated future water-use effects, using a groundwater model for the entire USP Basin, including an area of land near Redington in the Lower San Pedro Basin. Goode and Maddock developed a groundwater model that utilized earlier modeling studies by Putman and others (1988), Vionnet and Maddock (1992), and Jahnke (1994). They ran a number of development scenarios, ranging from relatively low groundwater use to relatively high use. Goode and Maddock used different methods of estimating mountain front recharge, phreatophyte use, and agricultural use than Corell and others (1996). The Goode and Maddock model also estimated agricultural acreage using a 1997 Landsat image. They estimated higher agricultural groundwater demands than did Corell (1996), even for the common area of both models. No ground-truthing was conducted for the Goode and Maddock model (Thomas Goode, University of Arizona, personal commun. to Frank Putman, ADWR, February, 2003). The higher agricultural demand estimate resulted in simulation of greater groundwater level declines in their model projections. Goode and Maddock's agricultural groundwater demand was about 113,000m^3/d (about 33,400 acre-feet per year). Their model also simulated agricultural recharge of 30% of the groundwater demand, so their net agricultural groundwater use was about 23,400 acre-feet per year.

Goode and Maddock (2000) published estimated effects on the groundwater system in their report. Using a high water use scenario, the model showed drawdowns near Sierra Vista and Fort Huachuca of about 15 meters (49 feet) between 1997-2000 and 2020, and drawdowns of 5+ meters (16+ feet) near Benson. Using lower population growth and water use estimates resulted in groundwater level declines of about 5 meters (16 feet) near Sierra Vista during this same period, and groundwater level rises of about 3 meters (10 feet) near Benson.

5.2 ADWR Current Findings and Projections

ADWR's review of measured data and recent studies indicates that none of the predictive studies discussed above precisely forecasted current hydrologic conditions in the USP Basin. Groundwater modeling is an important tool that can help analyze many interpretive and predictive hydrologic studies. It is important to understand the limitations and possible sources of error however, since all models are based on a set of simplifying assumptions, which limit their use for certain problems. Discussed below are Department findings based on recently measured data and analyses of recent studies in the Basin, as well as a comparison of the results of the predictive studies with current hydrologic conditions.

In the Sierra Vista area, the ADWR update of the USGS groundwater model (Putman and others, 1988) predicted a maximum decline of about 80 feet between 1986 and 2000, at a maximum rate of 6 feet per year. The actual maximum decline near Sierra Vista between 1990 and 2001 has been 15 feet, at an average of 1.4 feet per year, as shown in Figure 3-11 (Arizona Department of Water Resources, 2002b).

In the regional aquifer several miles west of the San Pedro River, the updated model (Putman and others, 1988) projected water levels in the year 2000 would rise up to 20 feet near Hereford, would decline by about 10 feet west of Lewis Springs, and would decline by about 10 feet west of Charleston. Actual measured changes in water levels between 1990 and 2001 have been on the order of –3 to +3 feet near Hereford, -3 to +4 feet west of Lewis Springs, and –4 to –6 feet west of Charleston as shown on Figure 3-11 (Arizona Department of Water Resources, 2002b).

Additional findings by Putman and others (1988) stated that the artesian head present in some portions of the regional aquifer underlying the floodplain alluvium of the San Pedro River had decreased somewhat over time due to groundwater development in these areas. In the Benson-Pomerene area, Barnes and Putman (2004) reported a modest water-level decline in the deeper (artesian) aquifer. Water-level changes in deep wells south of Pomerene ranged from a rise of 0.3 feet to a maximum decline of 19 feet, with most declines in the 4.0 to 9.0 foot range. In the St. David area, wells completed in the regional aquifer showed the least amount of change (Barnes and Putman, 2004). Hydrograph C in Figure 3-12 shows a gentle decline of the water level in the regional aquifer since 1990.

Putman and others (1988) stated that the shallow floodplain aquifer, which underlies the San Pedro River, showed no long-term declines in water level. The 1988 Putman and others report had predicted that the retirement of agricultural lands acquired by the U.S. Bureau of Land Management (BLM) in the SPRNCA would allow water levels in both the confined and unconfined regional aquifer to rise, particularly in the Hereford area, enhancing groundwater discharge rates to the floodplain alluvium. The Putman and others report (1988) also stated that the increase in flow may be offset if phreatophyte growth expanded into previously fallow land.

The shallow floodplain aquifer has shown variable changes of both rises and declines in water level from 1990 to 2001 (Barnes and Putman, 2004). This aquifer is recharged by the River and by groundwater discharge from the regional aquifer. Water levels in wells completed in the floodplain aquifer fluctuate seasonally in response to river flows, phreatophyte use, and pumpage. The recent drought conditions have reduced flow in the River, thus limiting recharge to the shallow floodplain aquifer and contributing to some observed declines (Barnes and Putman, 2004). North of Pomerene, water levels ranged from no change to a maximum rise of 11.1 feet, with an average rise of 4.7 feet. These measurements are mostly from shallow wells (Barnes and Putman, 2004). In the Benson-Pomerene area, water-level changes in the shallow aquifer ranged from a rise of 0.5 feet to a decline of 10.2 feet, with most declines in the 1.0 to 5.0 foot range. South of St.

David, declines in the 1 foot per year range have been recorded in the shallow aquifer. The floodplain aquifer from the U.S.-Mexico border to State Route 90 has shown little change since 1990. The Palominas and Hereford area reflect water-level changes ranging from rises of 7.0 feet to declines of 4.9 feet, with most wells showing a change of plus or minus 3 feet (Barnes and Putman, 2004). Hydrograph S of Figure 3-12 reflects the stable water-table conditions in the Palominas area. This hydrograph also shows that these water levels decline in dry seasons and dry years, but that they recover to their previous high levels following flood events of the San Pedro River.

Corell studied five alternative development scenarios for the period 1990-2030 that ranged from relatively low growth and low water use to relatively high growth and high water use (Corell, 1996). Corell's worst-case scenario of high growth, high evapotranspiration, and no recharge showed a 90 foot water-level decline in the Sierra Vista area by the year 2030. Other model assumptions for this scenario in 2030 included a population projection of 78,000, groundwater pumpage of 14,100 acre-feet per year, and riparian use of 10,000 acre-feet per year. In comparison, the Department's current projections for the year 2030 assume a higher population of 92,000, higher groundwater use of 23,400 acre-feet per year, artificial recharge of 5,100 acre-feet per year, and lower riparian use of 7,700 acre-feet per year. From 1990-2001, the measured water-level decline rate in the Sierra Vista area was less than 1 foot per year. Department projections show a linear increase in both population and groundwater demand. Assuming a decline rate of 1 foot per year and all other conditions remaining constant, a water-level decline in the Sierra Vista area of about 40 feet would be expected for the period 1990-2030.

The Goode and Maddock study modeled the northern part of the sub-basin, but as discussed, agricultural use has actually reduced far below their assumptions. Goode and Maddock used a net agricultural groundwater demand of about 23,400 acre-feet in their model, which led to an overestimate of groundwater declines within the USP portion of their scenario. By way of contrast, ADWR's estimate of consumptive (net) agricultural groundwater use for 2002 is about 7,500 acre-feet for the USP Basin. In their high water use scenario, Goode and Maddock eliminated agriculture within one mile of the San Pedro River. This run showed an estimated groundwater decline in the Benson area of up to 50 feet by 2020. The most recent water-level survey conducted by the Department showed that in the Benson-Pomerene area, wells completed in the shallow aquifer showed changes ranging from a rise of 0.5 feet to a decline of 10.2 feet between 1990 and 2001, with most declines in the 1.0 to 5.0 foot range. For the same period, water-level changes in deep wells in the Benson-Pomerene area ranged from a rise of 0.3 feet to a decline of 18.9 feet, with most declines in the 4.0 to 9.0 foot range (Barnes and Putman, 2004).

This review demonstrates that caution must be exercised when utilizing model results since all of the studies discussed here made one or more predictions that differ substantially from current conditions. Ongoing groundwater level measurement and updated water demand and supply data are also critical components in evaluating water resource conditions and in water management decision-making.

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CHAPTER 6

EVALUATION OF ACTIVE MANAGEMENT PRACTICES

This Chapter evaluates whether active management area (AMA) practices are necessary to preserve the existing supply of groundwater for future needs, A.R.S. § 45-412(A.1), one of the three criteria under which the director may propose to designate a subsequent AMA. It includes a brief background on the history, management and structure of existing AMAs and information on regulatory practices or programs. Examples from the geographically closest AMAs, the Santa Cruz and Tucson AMAs are provided. In the subsequent sections of this Chapter, each program or practice is described in detail along with its potential effect on the Upper San Pedro Basin groundwater supply. For the purpose of this evaluation it is assumed that programs within existing AMAs would be applicable to a subsequent AMA.

6.1 History, Management and Regulatory Structure

To address groundwater depletion in areas of high water demand, the Arizona legislature passed the 1980 Groundwater Management Act and created the Arizona Department of Water Resources to implement the provisions of the Groundwater Code. The Code established four initial active management areas in areas where groundwater depletion is most severe. The initial AMAs were the Phoenix, Pinal, Prescott and Tucson AMAs. A fifth AMA, the Santa Cruz, was formerly part of the Tucson AMA and was established by legislation in 1994.

AMAs are regulated under provisions of the Groundwater Code and each has a management goal. The management goal of the Phoenix, Prescott and Tucson AMAs is safe-yield by 2025. Safe-yield, as defined in the Code, means "to achieve and thereafter maintain a long-term balance between the annual amount of groundwater withdrawn in an active management area and the annual amount of natural and artificial groundwater recharge in the active management area." A.R.S. § 45-561(12). The management goal of the Pinal AMA is to allow development of non-irrigation uses and to preserve the existing agricultural economies for as long as feasible, consistent with the necessity to preserve future water supplies for non-irrigation uses. The Santa Cruz AMA management goal is to maintain a safe-yield condition and to prevent local water tables from experiencing long-term declines. The management goal for a subsequent AMA, and the number of years in which the goal is to be achieved, must be established by the director within thirty days of the designation. The management goal for a subsequent AMA can be adopted only after public hearings are conducted. A.R.S. § 45-569.

Water management efforts in AMAs focus on practices to attain the management goal, through conservation, augmentation and recharge programs and the renewable supply utilization requirements under the Assured Water Supply (AWS) program. In the existing AMAs there are a number of issues and challenges related to goal attainment.

The AMA practices discussed in this Chapter are in effect in existing AMAs and include the following:

- Groundwater rights and permits including metering, reporting and fees.
- Well regulations.
- Agricultural land development restrictions.
- Groundwater management plans, which include agricultural, municipal and industrial water conservation programs, an augmentation program, groundwater quality assessment, and a water management assistance program.
- Assured water supply program requirements for new subdivisions to have long-term dependable water supplies consistent with the management goal.
- Transportation of groundwater between groundwater basins and sub-basins.

Within existing AMAs, federal facilities (federally owned military reservations, hospitals, etc.) generally have voluntarily complied with many of the provisions of the Code and of the management plans.

While the Groundwater Code is comprehensive, it does not contain detailed instructions on how to manage water resources. Instead, it provides a framework from which water management decisions are made in the AMAs. The Department and the water users, through the development and implementation of the management plans and community-based decisions, establish the strategies that lead to efficient water management and achievement of management goals.

6.2 Active Management Practice: Groundwater Rights and Permits

6.2.1 Background

Types of Rights and Permits

Within an AMA, legal authority is required to withdraw groundwater from a non-exempt well (a well equipped with a pump with a capacity larger than 35 gallons per minute). The Groundwater Code established grandfathered groundwater rights, service area rights and groundwater withdrawal permits to provide legal withdrawal authority.

There are three types of grandfathered groundwater rights: 1) irrigation grandfathered groundwater rights, 2) Type 1 non-irrigation grandfathered rights, and 3) Type 2 non-irrigation grandfathered rights. All grandfathered rights are based on historic groundwater withdrawals. In the five existing AMAs, the historic period is from January 1, 1975 through December 31, 1979. If the director initiated the procedure for designating a basin as an AMA, irrigation rights would be based on the five-year period preceding the date of the notice of the initiation of designation procedures. A.R.S. § 45-465(A). For subsequent AMAs, if irrigated land is retired from irrigation use in anticipation of a non-irrigation use prior to AMA designation, or after subsequent AMA designation but prior to inclusion of the land within the exterior boundaries of the service area of a city, town or private water company, it could be eligible for a Type 1 right. To be eligible, the land must be held under the same ownership, and a development plan for the proposed non-irrigation use must be filed with the Department by a specified date. A.R.S. §§ 45-463(B) and 45-469(A). Type 2 rights may be issued for non-irrigation uses that existed in any one of the five years preceding designation. A.R.S. § 45-464. Groundwater withdrawal permits may be obtained for new non-irrigation uses for limited periods of time if certain conditions are met. A.R.S. §§ 45-514 through 45-519.01.

- *Irrigation grandfathered groundwater rights* establish the right to use groundwater to irrigate specific acres of land, which must have been irrigated with groundwater during the historic period. Land without an irrigation grandfathered right may not be irrigated with groundwater. An irrigation grandfathered right may not be sold apart from the associated land. The maximum annual volume of water that can be used is based on the irrigated acres, the water requirement of the historic crop and irrigation efficiency. Irrigation rights may be retired to a Type 1 right.

- *Type 1 non-irrigation grandfathered rights* establish the right to use groundwater for non-irrigation purposes. Type 1 rights are associated with farmland that has been retired from irrigation for a non-agricultural use. If the farmland is retired after the date of designation of the AMA, the irrigated land being retired must be located outside the service area of a city, town or private water company at the time the development plan is filed with the Department. A Type 1 right may not be sold apart from the associated land. The maximum amount of water that may be pumped each year using a Type 1 right is three acre-feet per acre. A Type 1 right is appurtenant to the retired farmland, which means that the groundwater must be withdrawn from the land or used on the land.

- *Type 2 non-irrigation grandfathered rights,* similar to a Type 1 right, establish the right to pump groundwater from a well for non-irrigation purposes. However, the right is based on historic groundwater pumping for a non-irrigation use and the volume of the rights is based on the maximum amount pumped in any one of the five historic years. Type 2 non-irrigation rights are the most flexible grandfathered right because they can be sold separately from the land that they were perfected on and may be used at any location. However, the owner of a Type 2 right may only withdraw groundwater from a location within the same AMA in which the historic withdrawals occurred. It is possible to lease all or a portion of a Type 2 right, but if the right is sold, it must be sold in its entirety. There are also mineral extraction Type 2 rights and electrical power generation Type 2 rights. These rights can also be transferred within an AMA but only for the specific purposes of the right. For example, a mineral extraction Type 2 right can not serve as a legal authority to pump water to serve a golf course.

In addition to grandfathered groundwater rights, the Groundwater Code provides for other legal methods to withdraw groundwater beyond historical use: service area rights and groundwater withdrawal permits.

- *Service Area Rights* allow cities, towns, private water companies and irrigation districts to withdraw groundwater to serve customers. The service area is generally the area of land with an operating distribution system. Holders of service area rights have the right to withdraw as much groundwater from within their service area as needed to serve their customers, subject to conservation requirements in the management plans and any applicable limitations imposed by the AWS Rules.

- *Groundwater withdrawal permits* for non-irrigation uses may be applied for by persons who require more water than what may be withdrawn pursuant to any available grandfathered rights or from an exempt well. If the criteria for the withdrawal permit are met, the director of ADWR is required to issue a permit for certain types of new or expanded non-irrigation uses of groundwater. Groundwater withdrawal permits specify limits on the duration and amount of withdrawals.

Metering, Reporting and Fees

With a few exceptions, any person withdrawing groundwater from a non-exempt well in an AMA must meter and report water use annually to ADWR. For example, groundwater withdrawals pursuant to an irrigation grandfathered right of ten or fewer acres are not required to be measured unless groundwater withdrawn from the well is also used pursuant to a service area right or another irrigation grandfathered right that is required to meter and report withdrawals. A.R.S. § 45-604(D). There are various types of measuring devices including those that are permanent or portable, installed in the pipeline or in an open ditch, and which can measure volume of flow or rate of flow. The device must comply with the provisions of the Department's measuring device rules, A.C.C. R12-15-901.

Pumpage and other required information is reported in the Annual Water Withdrawal and Use Report, or "Annual Report". The required information includes the amount of water pumped and an estimate of the energy needed to produce that amount of water and any other sources of water used. The information reported is used by ADWR to calculate compliance with conservation requirements and to calculate groundwater withdrawal fees.

There are a number of specific reporting requirements depending on the type of user. For example, a turf-related facility (a facility with more than ten acres of water-intensive landscaping such as a golf course), must report the number of acres of turf, the total water surface area (ponds), the number of acres that are overseeded, and the year the facility was constructed.

Some of the reporting information requires separate metering of users or uses. For example, large water providers are required to limit their distribution system losses to no more than 10%. This requires the metering of water deliveries to most of their service connections. This is an important tool in determining if there are leaks in the system, illegal connections, evaporation or leakage from storage ponds or tanks, etc. Monitoring and reporting requirements for each category of user regulated under the management plans are contained in the management plan in the five existing AMAs.

The Groundwater Code requires that each year the director of ADWR levy and collect a fee from each person with a right to withdraw groundwater (except for irrigation rights of less than ten acres) in an AMA. This fee cannot exceed five dollars per acre-foot. Withdrawal fee monies are used for administration and enforcement of the Groundwater Code, for augmentation of the water supply, for conservation assistance and for monitoring and assessing groundwater conditions. Fees may also be collected for purchasing and retiring grandfathered rights if such a program is included in the management plan for the AMA. Current fees in the AMAs range from $2.00 to $3.00 an acre-foot. Owners of “exempt” wells are not required to meter, report, or pay fees on their groundwater withdrawals. An exempt well is defined in the Groundwater Code as a well with a maximum pump capacity not more than 35 gallons per minute. The term “exempt” refers to the fact that withdrawal of water from these wells is generally exempt from regulation.

In addition to the groundwater withdrawal fee, the director annually levies and collects a water quality assurance fee from each person who owns a Type 1, Type 2 or groundwater withdrawal permit. This fee is collected and transmitted to the Arizona Department of Environmental Quality’s WQARF fund to help support cleanup of contaminated sites in Arizona. The water quality assurance fee is $2.12 per acre-foot. A.R.S.§ 45-616.

6.2.2 Potential Effect of the Active Management Practice on Basin Groundwater Supply

- A groundwater rights system would quantify and limit the maximum amount of annual withdrawals possible from non-exempt wells for agricultural and some industrial uses. It would also specify the type of use to which the water could be beneficially used. This would establish a limit on certain groundwater withdrawals.

  However, the Groundwater Code provisions are not intended to prevent expansions of industrial uses. Although there is a limit on the amount of groundwater that can be withdrawn for industrial uses pursuant to grandfathered groundwater rights, industrial users can obtain groundwater withdrawal permits for new or expanded uses if other sources of water are not reasonably available. In addition, the ability to convert rights to other uses and to move Type 2 rights provides opportunity for growth and flexibility in the industrial sector.

- Farms with two or more acres that were irrigated with groundwater at any time during the five years preceding the initiation of designation procedures would be entitled to a certificate of irrigation grandfathered right. Similarly, existing service areas and other non-irrigation water uses would be entitled to a groundwater right.

- Municipal groundwater use could increase because service area rights do not have a volumetric groundwater withdrawal limit and new service area rights can be established. Municipal volumes may increase as the population served increases but are capped by gallon per capita per day conservation requirements discussed in section 6.5.3 and are subject to assured water supply requirements discussed in section 6.6.

- New large non-residential groundwater users such as golf courses and power plants would be required to obtain a groundwater withdrawal permit or appropriate Type 1 or Type 2 right if served from wells at the facility.

- There would be a variable economic impact associated with metering non-exempt wells and paying groundwater withdrawal fees.

  A typical wellhead meter cost is approximately $500. In addition to that initial cost there would be meter maintenance costs.

  There are approximately 27,000 residential and commercial water provider connections in the Basin (not including Fort Huachuca). If a withdrawal fee of $3.00 per acre-foot were applied to the estimated year 2002 water provider demand of 11,200 acre-feet, there would be a total cost to all water providers of $33,600 or about $1.25 per connection per year. The withdrawal fee is levied on the water provider and could result in an increase in water bills.

  The estimated agricultural groundwater demand in 2002 was about 7,500 acre-feet. A withdrawal fee would have a larger financial impact on an individual farmer although typically the amount of the withdrawal fee is a small percentage of the overall cost of operation. Water users have some control over the amount of the fee by how efficiently water is managed.

- Non-exempt well metering and reporting requirements provide important information on regional and local groundwater demand including trends. The data would be used to develop management plans and provide a way to measure the impact of conservation practices and weather on water use. The demand estimates in this report were necessarily based on a variety of different sources and assumptions because of a lack of metered and consistently reported information.

- Where deliveries or points of use are required to be measured, metering allows for the calculation of lost and unaccounted for water. Most deliveries to water company customers are already metered. However, having a regulatory limit on lost and unaccounted for water would encourage water companies to identify and repair leaks and replace underreporting meters which typically translates into monetary and water savings over time. In cases where point of use meters would be required there would be associated installation, maintenance and energy costs.

- It is estimated that approximately 22,500 acre-feet of water use in the Basin, or 72%, could be subject to water rights requirements, metering and payment of fees. Exempt well use, Fort Huachuca use and San Pedro Golf Course use (assuming 100% effluent utilization) are not included in this estimate. This estimate assumes that no agricultural user utilizes 100% surface water. A person who uses 100% surface water or effluent does not need a grandfathered groundwater right and is not subject to conservation requirements, metering and reporting requirements or withdrawal fees.

6.3 Active Management Practice: Wells

6.3.1 Background

In AMAs, there are regulatory distinctions between wells equipped with a pump that can pump more than 35 gallons per minute (gpm), "non-exempt wells," and those that are equipped to pump less, "exempt wells." Withdrawal of water from a non-exempt well requires a legal authority, metering and reporting as discussed in the preceding section.

With certain exceptions, drilling a non-exempt well requires a well drilling permit and is subject to well spacing and well impact rules, R12-15-830. The Groundwater Code requires that applications to drill most non-exempt wells be approved only if the proposed well will not cause "unreasonably increasing damage to surrounding land or other water users from the concentration of wells." A.R.S. § 45-598(A). This provides some measure of protection to existing well owners. Under the Department's well spacing and well impact rules, an application to drill a new non-exempt well must be denied if the new well will cause more than twenty-five feet of additional drawdown at an existing well over a five-year period. If the well will cause between ten and twenty five feet of drawdown at an existing well over a five year period, the application must be denied unless the Department determines that the existing well will not be unreasonably impacted because of specific factors such as economic impact and current depth to water. The application must also be denied if the director determines that the proposed well would cause an unreasonable and adverse impact from additional regional land subsidence or migration of poor quality water. Similar protections do not exist outside of active management areas.

Exempt wells within AMAs or any well outside of an AMA must obtain a Notice of Intention to drill (NOI). Legal authority or a well impact analysis is not required. There is no requirement to measure or report water withdrawals. Within an AMA, withdrawals of groundwater from exempt wells drilled after April 28, 1983 and used for non-residential purposes cannot exceed ten acre-feet per year (3.26 million gallons). Exempt wells for domestic purposes could potentially withdraw 56 acre-feet per year if operated continually (18.25 million gallons).

Within AMAs, except under specific circumstances, not more than one exempt well serving the same purpose at the same location can be drilled. This allows for separate wells for stockwatering and domestic purposes. In addition, exempt wells may not be linked together by a pipeline (to prevent circumvention of the requirement for a water right or permit to pump large volumes of water). Similar restrictions do not exist outside AMAs as long as the water is put to reasonable and beneficial use.

Certain registration and drilling requirements apply statewide. An application for an authority to drill must be filed (either an NOI or an Application for a Drilling Permit).

The application process results in automatic registration of the well. A licensed well driller must drill the well. A comparison of the requirements for exempt and non-exempt wells, within and outside of AMAs, is summarized in Table 6-1.

Table 6-1. Well Requirements Within and Outside of AMAs.

Requirement	Wells with Pump Capacity ≤ 35 gpm **in or outside AMA** (exempt)	Wells with Pump Capacity > 35 gpm **in AMAs** (non-exempt)	Wells with Pump Capacity > 35 gpm **outside AMAs** (non-exempt)
Legal authority needed (right or permit)	No	Yes	No
Metering requirement	No	Yes	No
Well Impact Analysis	No	Yes	No
Withdrawal fee	No	Yes	No
Multiple wells	Some restrictions in AMAs	No restrictions	No restrictions
Licensed well driller	Yes	Yes	Yes
Authority to drill/registration	Yes	Yes	Yes

6.3.2 Potential Effect of the Active Management Practice on Basin Groundwater Supply

- Domestic exempt well users, which include most household and stock watering users, would experience little impact if the Basin were designated as an AMA. There would be a restriction on multiple wells for the same use at the same location. Metering existing or new exempt wells would not be required.

- Commercial exempt well users whose wells were drilled after April 28, 1983 would be restricted to pumping no more than ten acre-feet of water per year. In cases where more than 10 acre-feet would be required for the use, the user would be required to obtain a Groundwater Right or Permit to serve the use (see section on Groundwater Rights and Permits).

- Non-exempt well users would be required to meter their wells, annually report to the Department the amount of water used and pay a groundwater withdrawal fee (see section on Groundwater Rights and Permits).

- There would be some water level drawdown protection for both exempt and non-exempt well owners from the drilling of nearby large wells due to the requirement to comply with the Department's well spacing and well impact rules.

6.4 Active Management Practice: Agricultural Land Development Restrictions

6.4.1 Background

Within the five existing AMAs, land that was not irrigated between January 1, 1975 and January 1, 1980 may not be brought into production with any water, with few exceptions. A.R.S. § 45-452. For example, in some instances, land that has been damaged by flood events may be exchanged for other land. Also, land not irrigated during the historic period may be irrigated with surface water pursuant to a decreed or appropriative surface water right established before June 12, 1980. The same restrictions on expansion of irrigated acres are in effect in areas of the state designated as Irrigation Non-Expansion Areas (INAs). Only lands irrigated at any time during the five years preceding the date of notice of designation can be irrigated. A.R.S. § 45-434. There are three INAs in the state: the Douglas, Harquahala and Saint Joseph INAs (see Figure 1-1). In INAs however, agricultural lands are not subject to water duty conservation requirements, and while water use must be metered and reported to the Department, groundwater withdrawal fees are not collected.

6.4.2 Potential Effect of the Active Management Practice on Basin Groundwater Supply

Table 6-2 shows that since 1985 there has been a substantial reduction in the number of irrigated acres within the Basin with a corresponding reduction in agricultural demand. Irrigated agricultural land has declined in the Basin due to establishment of the San Pedro Riparian National Conservation Area, development, purchase of irrigated land for conservation purposes, and economic conditions. Future agricultural demand is difficult to predict but based on historic trends, restrictions on bringing new lands into agricultural production may not present a significant impact on agricultural activity in the Basin. Agricultural demand is still a significant water use in the Basin however, representing about 32% of both the total Basin demand and the Basin net use groundwater demand. Increased efforts to acquire and retire agricultural lands without subsequent irrigation at a different location and efforts to increase agricultural efficiency would further reduce agricultural demand.

Table 6-2. Reduction in Irrigated Acres in the USP Basin, 1985-2002.

Area	**1985**		**2002**		**Percent Reduction**
	Irrigated Acres	Demand (af)	Irrigated acres	Demand (af)	Irrigated Acres
Sierra Vista sub-area	2,100	5,900	800	2,500	62%
Benson sub-area	3,200	10,800	2,200	7,300	34%
Upper San Pedro Basin	5,300	16,700	3,000	9,800	45%

6.5 Active Management Practice: Management Plan

6.5.1 Background

For subsequent AMAs, the director must promulgate an initial management plan within two years after designation. If designation is based on subsidence or the need for AMA practices, the plan must include measures for reducing groundwater withdrawals, which follow as closely as practicable the program set forth for the five existing AMAs in A.R.S. §§ 45-564 through 45-568. If the designation is due to threatened or actual water quality degradation from groundwater use, the director must include in the plan a program to prevent or ameliorate the problems. A.R.S. § 45-569.

Sections 45-564 to 45-568.02 of the Code contain requirements for agricultural, municipal and industrial users that must be included in the management plans. Agricultural uses are uses of groundwater for the irrigation of two or more acres of land to produce plants for sale or for human or animal consumption. Regulated agricultural users have irrigation grandfathered rights. The municipal program regulations apply to "municipal water providers;" cities, towns, private water companies and irrigation districts that serve water for residential, commercial or industrial uses. Regulated municipal water providers have service area rights. Industrial uses are defined as a non-irrigation use of water not served by a municipal water provider. Industrial users have their own wells and withdraw groundwater pursuant to Type 1 or Type 2 rights or groundwater withdrawal permits and include golf courses, sand and gravel facilities and large-scale power plants, large cooling towers and large metal mines.

The Code generally requires that each consecutive management plan contain more rigorous, but reasonable, water conservation and management requirements. The management plans contain a discussion of the AMA programs and policies that are intended to achieve the AMA's management goals. Background information, water use data, and water supply and water use projections are also contained in the management plans. The plans provide the framework for the day-to-day implementation of Code mandates and ADWR policies for each AMA.

Each AMA has a Groundwater Users Advisory Council (GUAC), a five-member board appointed by the Governor to provide advice and recommendations on water resource issues. The GUAC members serve six-year terms, must reside within the AMA, and represent the local groundwater users. These councils, in addition to a variety of technical advisory committees and the general public, all have input into the process of drafting the management plans. The director must hold public hearings on each management plan in each AMA prior to adoption of the plan. A.R.S. § 45-570.

The Code specifies that the management plans include:

- Conservation requirements for irrigation users, which may include water duties based on the amount of water reasonably needed to grow historic crops, or implementation of certain agricultural water management activities.

- Conservation requirements for large municipal providers, (cities, towns, private water companies and irrigation districts serving more than 250 acre-feet of water per year for municipal uses), which may include reductions in per capita water use or implementation of specific conservation programs within the service area.

- Reasonable conservation requirements for small municipal providers, (cities, towns, private water companies and irrigation districts serving less than 250 acre-feet of water per year for municipal uses), which include minimizing waste, maximizing efficiency and reuse of water supplies.

- Conservation requirements for industrial users based on the use of the latest commercially available conservation technologies that are economically reasonable.

- A water supply augmentation program, which may include incentives for artificial groundwater recharge. Groundwater withdrawal fees may be used to finance the program.

- An assessment of groundwater quality within the AMA with the cooperation of the Department of Environmental Quality.

- A water conservation assistance program. Groundwater withdrawal fees may be used to finance the program.

- For the Santa Cruz AMA, the inclusion of criteria for ensuring that new or replacement wells in a new location are consistent with the AMA goals.

- A program (optional) for the purchase and retirement of grandfathered rights by the Department no earlier than January 1, 2006.

Regulated agricultural, municipal and industrial users can apply for a variance or administrative review of their conservation requirement. A variance gives a person additional time to comply due to economic reasons, while an administrative review can result in an adjustment of the requirement.

6.5.2 Agricultural Conservation Program

Program in AMAs

Small pastures, gardens or other irrigated agricultural land less than two acres in size do not meet the Code definition of irrigated land. Therefore, these lands are not regulated and do not require an irrigation grandfathered groundwater right (IGFR) to withdraw and use groundwater. Legislation passed in 1994 exempted farms with ten or fewer irrigation acres from being assigned a regulatory irrigation water duty. These farms are not required to measure water withdrawals, file annual water use reports or pay withdrawal fees although they retain their irrigation grandfathered groundwater right.

The Base Agricultural Conservation Program assigns irrigation users with over ten irrigation acres a regulatory water duty, or acre-foot per acre maximum water allotment. The irrigation water duty is the quantity of water reasonably required to irrigate the crops historically grown. It is calculated using the following formula:

$$\text{Irrigation water duty} = \frac{\text{total irrigation requirement per acre}}{\text{assigned irrigation efficiency}}$$

Irrigation efficiency is affected by many variables including soil intake rate, type of irrigation system, slope, and crop type. The Code requires that the Department calculate the water duty using an efficiency of 80% unless there are limiting soils, excessive slopes or orchard crops.

Farmers are provided with flexibility to meet varying climatic conditions and changing agricultural market conditions through a flexibility account by which flex account credits and debits are accumulated. For example, if a farmer uses less water during a year than the allotment, the account is credited with the unused volume, which can be used any time in future years on the farm. Farmers may also sell and transfer the previous years flex credits to other farmers in the same AMA subject to certain restrictions.

Farmers may apply for regulation under an alternative program that allows for use of more water in exchange for a limit on flex credit accumulation and a high level of management. There are two alternative programs: the Historic Cropping Program and the Best Management Practices (BMP) Program. The BMP Program replaces the allotment completely with implementation of specific on-farm conservation practices.

In addition to requirements for individual irrigation right holders, there are conservation requirements for irrigation distribution systems that are intended to minimize losses and use and deliver water efficiently. Lining of irrigation canals with a material as efficient as well-maintained concrete is required, or canal losses must be limited to no more than 10%. Monitoring and reporting requirements for districts require submittal of a system map showing portions of the canal that are lined and unlined, miles of canal, total water withdrawn, diverted, received and delivered annually, and an annual estimate of lost and unaccounted for water.

Potential Effect of the Active Management Practice on Basin Groundwater Supply

- Regulated farms (farms of 10 or more acres in size) would be assigned an irrigation water duty based on the consumptive use of crops historically grown and a water use efficiency level that could require improved water management practices and/or investments in irrigation systems.

  Levels of agricultural efficiency or actual water application rates in the Basin are not well known because water use is not typically metered and is not reported. Estimates in the Hydrographic Survey Report for the San Pedro River Watershed (San Pedro HSR, 1991a) are that a "well maintained" sprinkler irrigation system is approximately 58% efficient while a "well maintained" flood system without tailwater recovery is 45% efficient in the Basin. Potentially achievable irrigation efficiencies range from 60% for a sloped field with no tailwater recovery system, to 75% for a sprinkler system, and 85% for level basin irrigation (Second Management Plan, Tucson AMA, January 1991). In existing AMAs, water duties are set using an assigned efficiency factor of 80% with adjustments made for limiting factors such as saline soils. It is likely that a higher level of conservation would be required by agricultural irrigators in the Basin to meet the water duty requirement.

- The alternative conservation programs that require the implementation of certain water management practices could require financial investments.

- Regulated farms would be subject to metering, reporting and fee requirements and the requirement to file for an Irrigation Grandfathered Right in order to continue to farm.

- The two irrigation water providers in the Basin would be subject to the canal efficiency and monitoring and reporting requirements.

  According to the San Pedro HSR, the Pomerene Water Users Association (PWUA) ditch is concrete lined in portions that carry both surface water and well water from private wells. The rest of the canal is unlined. The Saint David Irrigation District (SDID) canals are unlined. Estimates in the San Pedro HSR list about 6% losses for the SDID and about 2% for PWUA. If distribution system losses were greater than 10% then investments in distribution system improvements would need to be made. The monitoring and reporting requirements described above would require a minimal investment of time each year.

- Owners of irrigated acreage less than two acres in size could continue to farm without applying for a groundwater right, would not be regulated by a water duty requirement, and would not be required to meter and report water use. Estimates in the San Pedro HSR are that approximately 13% of the irrigated lands in the Benson sub-area and 57% of the irrigated land in the Sierra Vista sub-area consist of farms less than two acres in size.

- Agricultural conservation requirements would apply to all irrigated acreage in the Basin greater than 10 acres in size and irrigated with groundwater. The exemption from conservation requirements for farms with 10 or fewer irrigation acres that exists within the initial AMAs, is not specifically spelled out for subsequent AMAs. The Groundwater Code would need to be amended to extend the small farm water duty exemption to subsequent AMAs. Total irrigated acreage in the Basin was estimated at 3,000, but acreage of farm units less than 10 acres in size is not known.

6.5.3 Municipal Conservation Program

Program in AMAs

The base regulatory program for large municipal water providers (those pumping over 250 acre-feet per year) is a gallon per capita per day (GPCD) requirement. Large providers also have the option of selecting two alternative regulatory programs that include implementation of best management practices and either no GPCD requirement or only a residential GPCD requirement. To qualify for the alternative programs, a municipal water provider must agree to limit its groundwater use to a specified amount. Small municipal providers are required to implement a program to achieve general conservation goals including minimizing waste and encouraging water reuse.

Municipal providers regulated under the GPCD program are expected to decrease per capita use over time depending on their conservation potential; the higher the per capita use, generally the more potential there is to conserve. However, GPCD requirements take into account the individual water use characteristics of each service area. For example, a service area with a significant amount of high water use landscaping would not be assumed to use water at the same rate as a service area with predominantly low water use landscaping. Instead the requirement would assume that the provider would initiate a conservation program to promote efficient irrigation.

New residential users are assumed, on average, to use water at a model per capita use rate, utilizing low flow plumbing fixtures and low water use landscaping. The Third Management Plan (TMP) model use rate for new single-family home interior use in all AMAs is 57 GPCD. The exterior model use rate in the Tucson AMA is 118 gallons per housing unit per day (GPHUD), or roughly 49 GPCD. In the Santa Cruz AMA, the exterior model use rate is 107 (GPHUD), or about 33 GPCD. These rates are averages and some households may use water at rates much greater or less than this.

The assumed gallons per capita per day rates for existing residential users, new residential users, non-residential users and lost and unaccounted for water is combined into a total gallon per capita per day regulatory requirement. When calculating GPCD for regulatory purposes, effluent is subtracted as an incentive for its use. The average total per capita use in the Tucson AMA is about 170 and about 190 in the Santa Cruz AMA.

High per capita rates are not necessarily an indication of wasteful water use. Water providers that serve a high percentage of non-residential uses such as golf courses or industrial facilities typically have higher per capita rates because these uses do not have an associated population as do residential subdivisions. While the overall requirement is based on a number of assumptions and estimates about efficient water use, the water provider would not be required to implement specific conservation measures. This leaves the decision making on how to achieve the requirement up to the utility. The alternative programs that remove all or part of the GPCD requirement are, by contrast, prescriptive about the implementation of certain programs. However, there is some opportunity to tailor the alternative program to the individual service area.

There are regulations limiting the amount of lost and unaccounted for water for municipal water providers. Large municipal water providers are required to limit losses to 10% and small providers to 15%. This ensures that water is being used efficiently and can result in monetary savings on the part of the provider over time; lost water results in lost revenue.

<u>Potential Effect of the Active Management Practice on Basin Groundwater Supply</u>

- If the Basin were designated as an AMA, each large municipal water provider would receive a per capita conservation requirement based on efficient use of water by each type of user in the service area (residential, non-residential, turf-related facilities), tailored to the individual water use characteristics of the service area.

  Per capita water conservation requirements would apply to approximately 47% of the municipal water use in the Basin. Small water providers, exempt wells and Fort Huachuca would not be subject to a per capita requirement.

  Actual GPCD rates in the Basin are uncertain due to lack of information regarding actual water use and water provider population. Water provider populations may be estimated based on the number of residential connections and the 2000 Census person per housing unit (pphu) value for occupied housing units. This assumes a uniform pphu in the Basin, which can vary between service areas. Recognizing these uncertainties, it is estimated that GPCD use, the main measure of municipal conservation, varies from 80 to 196 among large providers in the Basin (Table 6-3). These GPCD rates include commercial use but not effluent use.

  It is not possible to predict what the actual regulatory per capita requirements would be for the large providers if the Basin were to become an AMA. This would require detailed water use information and an analysis of conservation potential in each service area. However, new population would be assumed to use water at the model use rate and this would be factored into the regulatory requirement. Percentage reductions required in the five existing AMAs have ranged from 0 to 38% over a ten-year management plan period. Providers are not expected to reduce GPCD use below a minimum level specified in each AMA management plan.

  There are a number of conservation programs underway in the Sierra Vista area. These include the Water Wise program, Sierra Vista toilet rebate program and efforts at Fort Huachuca that have reportedly reduced on-post water consumption by almost

45% since 1993. The County has budgeted for a Water Conservation Office and plans to fund water conservation rebates. To date, rebates are primarily offered through the Upper San Pedro Partnership conservation grants funds. Sierra Vista has made changes to its city code limiting turf use in new landscaping, requiring use of low water use plants, requiring recycling of water at commercial car washes and imposing other water use restrictions. The Upper San Pedro Partnership is investigating water consumption and reuse alternatives through a consultant study that will be integrated into a Conservation Plan.

Table 6-3. Estimated Large Provider Per Capita Use in 2002

Water Provider	Per capita use (est.)
Arizona Water Company – Bisbee	178
Arizona Water Company. – Sierra Vista	196
Bella Vista Water Company	178
Benson, City of*	80
East Slope Water Company	147
Fort Huachuca*	161
Huachuca City	124
Pueblo del Sol Water Company	124
Weighted Average	**158**

Note: Private water companies annually report water delivery and/or pumpage information is reported annually to the Arizona Corporation Commission. Water delivery information assumes 10% system losses to calculate well pumpage and GPCD rate. Public systems do not have annual reporting requirements.

* Effluent use not included. If effluent were included in the GPCD calculation, GPCD rates would be 152 for Benson, 207 for Fort Huachuca, and the average of all large providers would be 172.

- Lost water requirements would be imposed on all water providers. Annual reporting of water pumped and delivered would be required as well as meters at the wellhead and at point of delivery. This could mean investments in meter installation and meter reading and maintenance.

- Reporting of specific delivery information and payment of withdrawal fees as discussed in section 6.2 would be required with associated financial impact.

6.5.4 Industrial Conservation Program

Program in AMAs

Industrial users are generally facilities with their own wells that withdraw groundwater using a Type 1 or Type 2 grandfathered groundwater right or a groundwater withdrawal permit. The Groundwater Code states that the management plans must establish conservation requirements for industrial uses that are based on the use of the latest commercially available conservation technology consistent with reasonable economic return.

In the Third Management Plan for the existing AMAs, all industrial users are subject to general conservation requirements that prohibit single-pass cooling unless the water is reused, require the reuse or recycling of water if possible, require use of low-flow plumbing fixtures as required by state law and use of low water use landscaping to the maximum extent feasible. In addition, specific water conservation requirements apply to the following facilities that use at least some groundwater:

- turf-related facilities (golf courses, schools, parks and cemeteries $\geq$10 acres)
- metal mines (>500 acre-feet/year)
- dairy operations (monthly average $\geq$ 100 lactating cows/day)
- cattle feedlot operations (monthly average $\geq$100 beef cattle/year)
- large-scale cooling facilities ($\geq$1,000 tons)
- large-scale power plants (>25 megawatts)
- sand and gravel facilities (>100 acre-feet/year)
- new large landscape users (>10,000 square feet of water intensive landscape)
- new large industrial users (>100 acre-feet/year)

Turf-related facilities and large-scale cooling facilities that receive groundwater from a water provider are also regulated under the industrial program as an "individual user." This enables direct regulation of these high water use customers of water providers so that they use water as efficiently as facilities with their own rights or permits. The requirements for those industrial and individual users identified in the Basin are discussed below. These include turf-related facilities, a dairy and a large-scale cooling facility.

Turf-related facilities (golf courses, schools, parks > 10 acres)

Turf-related facilities are regulated through an acre-foot per acre maximum annual water allotment that assumes efficient management. In the Tucson and Santa Cruz AMAs, the allotment is based on 4.6 acre-feet per acre for turf, 1.5 acre-feet per acre for low water use plants and 5.8 acre-feet per acre for lakes. Lakes are typically used for storage at golf courses and must be sealed since 5.8 acre-feet per acre is based on evaporation only. New golf courses in the Tucson and Santa Cruz AMAs are limited to a maximum annual water allotment of 23.8 acre-feet per hole or 428.4 acre-feet for an 18-hole course. This ceiling indirectly limits the amount of acreage that can be irrigated. Existing golf courses are assigned an allotment based on the number of existing acres. Adjustments are made to the allotment for the establishment of newly turfed areas, to initially fill or refill a lake, for revegetation to establish plants that only need temporary watering, for leaching and for any reductions in turfed acreage.

When less than the allotment is used, because of wet weather or other reasons, the unused portion is credited to a "flexibility account." A credit balance of up to 20 percent of the facility's annual allotment can be accrued. When the weather or water management decisions result in a facility using more than its allotment, it can use these credits. If all the credits are used, a facility can accrue a debit balance of up to 20 percent of the allotment before a violation occurs. The flexibility account provides regulatory flexibility. There is also an effluent use incentive that allows more water to be used by facilities watered in part with effluent. This incentive allows each acre-foot of effluent to be counted as .7 acre-feet when calculating compliance with the allotment.

Large-Scale Cooling Facilities (≥1000 tons)

Large-scale Cooling Facilities (LSCF) are those with an aggregate cooling capacity of 1,000 tons or more. The minimum cooling unit that is added to create the aggregate total is 250 tons in size. Larger units are considered to have more conservation potential and chemical treatment and monitoring is more cost effective. Most LSCF's are served by a water provider and are termed individual users. As such, they are regulated under the industrial program. LSCF's are generally associated with hospitals, regional malls and other large commercial and industrial buildings.

The primary use of water at a LSCF is to absorb heat from a heat-generating process and dissipate it through evaporation. As the water evaporates, dissolved minerals become concentrated in the remaining water and it must periodically be discharged to prevent damage to the towers. This discharge is known as "blowdown." LSCF's are required to achieve either 120 mg/l of silica or 1,200 mg/l of total hardness in the recirculating water, whichever is reached first, before blowing down. The more the water is recirculated, the more is conserved. There are special provisions for the use of effluent or if meeting the requirement would result in damage or violation of environmental discharge standards due to a limiting constituent in the water besides silica or hardness.

Dairy Operations (monthly average >100 lactating cows/day)

Most of the water use at dairies is for the milking cycle, including cooling cows, udder washing, holding pen and parlor area cleaning and the cleaning of milk lines and milking equipment. Other uses are for drinking, feed preparation and dust control. Regulated dairies are assigned a maximum annual water allotment based on the water needs of lactating cows at a rate of 105 gallons per day, and non-lactating animals at a rate of 20 gallons per day. More water is allowed if milking is more frequent than 3 times a day or if additional water is needed for sanitation purposes. In consideration of weather variability there is a three-year averaging provision to determine compliance. As an alternative to the annual allotment requirement, a dairy can apply to be regulated under the Best Management Practices program, which requires implementation of specific conservation and management practices that maximize efficiency but does not include an annual allotment.

Potential Effect of the Active Management Practice on Basin Groundwater Supply

- There are 5 turf-related facilities, one dairy, and one large cooling facility in the Basin that would be subject to specific industrial conservation program requirements.

- All turf-related facilities would receive an acre-foot per acre maximum annual allotment based on the size of the course or acreage of the park.

  The City of Sierra Vista has Code requirements intended to limit water use by parks and golf courses (151.16.004). These limit turf at new golf courses to 5 acres per hole and limit ponds and lakes.

- AMA designation would likely have the biggest effect on new, rather than existing turf-related facilities because new facilities would need to limit the turfed acres to meet the turf facility allotment while existing facilities are assigned an allotment based on existing acreage.

- Any industrial facility that uses 100% effluent would not be subject to the conservation requirements. Turf-related facilities that use some, but less than 100% effluent may use more water than a facility watered with no effluent.

  The San Pedro Golf Course, the Mountain View Golf Course and Chaffee Parade Field use effluent. Mountain View and Chaffee used 100% effluent in 2002. Golf courses located on federal facilities in AMAs voluntarily comply with the turf allotment requirement.

- There are reportedly five sand and gravel operations in the Basin (Aggregates Manager, 2001 and ADWR field survey, 2003). The San Pedro HSR listed six facilities in 1991. At that time, all facilities used less than 100 acre-feet of water per year and therefore would not have been regulated under a management plan. Updated water use information is not available for the currently operating facilities. If any facility uses more than 100 acre-feet per year, it would be subject to sand and gravel facility conservation requirements.

- There are four cooling towers at the Apache Nitrogen Facility that would be regulated since they exceed 1,000 tons, either singly or in combination.

- All industrial facilities would be subject to metering, annual reporting, payment of withdrawal fees and to the basic industrial user requirements (*e.g.* reuse, recycle, limit single-pass cooling).

- Implementation of conservation requirements could require investments in conservation technologies and more efficient water management.

- Potentially regulated industrial users and individual users are shown in Table 6-4. The actual water use by most industrial users in the Basin is not known. Estimated volumes are shown in Chapter 4, sections 4.2.2 and 4.2.3 and water use assumptions are discussed in Appendix L. Individual facility owners can compare their water use with those in the table to determine the potential effect of the AMA practice.

Because facilities using 100% effluent are exempt from AMA conservation requirements, four turf facilities, the dairy and Apache Nitrogen appear to be the only potentially regulated industrial facilities in the Basin. Veterans Park, served by Sierra Vista, is an individual user. The other facilities are industrial users. These facilities used approximately 2,100 acre-feet in 2002. It is difficult to predict the effect of AMA conservation requirements without more specific information about current water use and acreage. Veterans Park appears to be within an AMA allotment.

Table 6-4. Existing Industrial/Individual Water Users in the USP Basin

Facility	Facility Size	Potential Allotment/Requirement (TMP requirements for AMAs)
Chaffee Parade Field *	10.25 acres	47.15 acre-feet
Mountain View Golf Course *	18 hole	4.6 acre-feet/acre for turf 1.5 acre-feet/acre for low water use plants 5.8 acre-feet/acre for lakes
Pueblo del Sol Golf Course	18 hole	"
San Pedro Golf Course*	18 hole	"
Turquoise Hills Family Golf Ctr.	18 hole	"
Turquoise Valley Golf Course	18 hole	"
Veterans Park	40 acres	184 acre-feet
Dairy (Pomerene area)	>100 lactating cows	105 GPD[+]/lactating cow 20 GPD/non-lactating animal
Sand and Gravel (4)	< 100 acre-feet/year	No sand and gravel requirements
Apache Nitrogen	4 Cooling Towers	120 mg/l of silica or 1,200 mg/l of total hardness in the recirculating water before blowing down

* Facilites use effluent. If effluent use is <100%, regulations apply.

\+ GPD=gallons per day

6.5.5 Augmentation and Recharge Program

Program in AMAs

Water augmentation activities encouraged by the management plans have resulted in the underground storage of large volumes of Central Arizona Project water and effluent in the Phoenix, Tucson, and Pinal AMAs. The goals of the augmentation program are to encourage the use of renewable water supplies, allow for flexible storage of supplies not currently needed, and to preserve groundwater supplies. Recharging renewable water supplies that would otherwise be unused provides a supply during periods of extended drought and may help meet water management objectives such as replenishing areas that have been over-pumped. Another program goal is to allow for the efficient and cost-effective management of water supplies by allowing the use of underground storage facilities for filtration and distribution of surface water rather than constructing surface water treatment plants and pipeline distribution systems.

Not all AMAs have access to large volumes of renewable water supplies. Neither the Santa Cruz or Prescott AMAs have access to Central Arizona Project (CAP) water, however both have access to imported water supplies. The Santa Cruz AMA receives an effluent supply from Mexico that is treated within the AMA. The Prescott AMA is statutorily authorized to import groundwater from the Big Chino Basin located north of the AMA.

Recharge is not limited to the AMAs. Anyone who wishes to store, save, replenish or recover water underground must apply for permits through the Department. There is currently one permitted facility in the Basin that recharges effluent, the Sierra Vista Water Reclamation Facility. Effluent and stormwater recharge is also underway at Fort Huachuca.

Incentives to facilitate the utilization of renewable supplies have been incorporated into the management plans, providing "breaks" in the conservation requirements for the use of effluent and CAP water under certain circumstances. Financial assistance is provided through the augmentation assistance program, supported by groundwater withdrawal fees, for selected entities implementing augmentation projects or studies that contribute to achieving the AMA management goal or resolving regional water management issues through augmentation.

Potential Effect of the Active Management Practice on Basin Groundwater Supply

- The only supply presently available in the Basin for augmenting the water supply is effluent. Some of the Basin's water management issues can be addressed by directly using or recharging as much reclaimed water as is hydrologically and economically feasible. The effluent supply will grow as the population grows but it originates from only about 23% of the total Basin use, interior use by the sewered population, and is insufficient to offset all potential demands.

- Basin water users already recognize the value of the effluent resource, utilizing it directly and recharging it to replenish the aquifer as shown in Table 6-5. The City of Sierra Vista Water Reclamation Facility was permitted in August 2001 to store 4,149 acre-feet per year for 20 years. (The permit volume will need to be amended to recharge the projected volume in 2030). In 2002 almost 1,500 acre-feet was recharged by Fort Huachuca and Sierra Vista. Both projects are intended to benefit the aquifer and there are no plans to recover this water.

  City of Benson and Fort Huachuca use effluent for turf irrigation. By 2010, consolidation of Bisbee wastewater treatment at Bisbee-San Jose and improvements and expansion of the collection system is anticipated to result in additional turf irrigation and recharge. In 2002, approximately 46% of the effluent resource was utilized, projected to increase to 95% by 2030. If 2030 projections are realized, effluent used directly and recharged will offset 18% of the total demand.

- There are cost and geographic issues associated with use of effluent supplies. Transporting effluent to where it can be used directly may be cost prohibitive, making direct recharge a more viable option. Creation of a replenishment or water augmentation district could help offset the costs incurred in recharging effluent.

- The only other potential source of water to augment existing supplies in the Basin are those that could be imported from outside the Basin. However, there are substantial impediments to transporting groundwater from an adjacent basin as described in Section 6.7, Transportation of Groundwater.

  CAP water is physically distant and even if available through contract or purchase, would be expensive to transport. Estimates generated for the Upper San Pedro Partnership are $121.7 million for construction of a CAP pipeline and $16.4 million in annual costs (Fluid Solutions and BBC Research and Consulting, 2002). The Bureau of Land Management is currently updating a study it conducted in 1993, evaluating costs and feasibility of a CAP pipeline to the Basin (USBR, 1993).

Table 6-5. Estimated Effluent Production and Use in the USP Basin.

City/Town	Est. 2002 production (acre-feet)	2002 uses (acre-feet)	Est. 2030 production (acre-feet)	Est. 2030 uses (acre-feet)
City of Sierra Vista	2,800	960 recharge	4,100	4,100 recharge
Fort Huachuca	1,000	420 turf 540 recharge	800	370 turf 430 recharge
City of Tombstone	130	[130 IR]	140	[140 IR]
Huachuca City	150	[150 evaporated]	210	210 recharge
City of Bisbee	610	[610 evap./IR]	910	570 turf 340 recharge
City of Benson	560	380 turf	1,100	1,100 turf and other
Naco	80	[80 evaporated]	100	[100 evaporated]
Bachmann Springs	0	0	180	180 turf
Total effluent	5,300		7,700	
Total recharge		1,500		5,100
Total turf irrigation		920		2,200
Total effluent use		2,420		7,300

Note: IR = incidental recharge

6.5.6 Groundwater Quality Program

Program in AMAs

The Arizona Department of Environmental Quality is the lead state agency on water quality issues and compliance. However, water quality is an important component in water supply management, which is the responsibility of the Department. The management plans explain the Department's responsibilities that include enhancement of groundwater quality protection programs, assistance in the cleanup of contaminated areas and assistance in matching water quality with the highest beneficial use.

The Department also has responsibility for water management activities provided for in the 1997 Water Quality Assurance Revolving Fund (WQARF) Program legislation. The purpose of this program is to protect the waters of the state from hazardous substances. The management plan describes the Department's role in implementing the WQARF program including providing data and support to ADEQ, assistance in the selection of remedial activities that meet water management objectives and identification of potential end users of the remediated water. The management plans also contain an assessment of water quality conditions and issues in the AMA.

Potential Effect of the Active Management Practice on Basin Groundwater Supply

The Apache Powder site is a federal Superfund site where soil and groundwater contamination has occurred. Explosives manufacturing occurred in the past, and currently the plant manufactures fertilizer and nitric acid. A wetland has been constructed to treat nitrate-contaminated groundwater. Perchlorate contamination in groundwater has also been found in the southern area of the Apache Powder site. There are two sites of possible contamination on Fort Huachuca that are being monitored, the South Range Landfill and the East Range Mine Shaft. Several monitoring wells are sampled periodically at each site and there is no evidence of aquifer contamination above the Aquifer Water Quality Standards.

- Because the Department has limited water quality authority, an AMA designation would have little impact other than the WQARF fee assessment for certain users, described in section 6.2.

- The AMA management plans are required to contain a water quality assessment, which would provide useful information on basin conditions. The management plans also provide some incentives to use poor quality water and to reuse wastewater in the regulatory programs.

6.5.7 Water Management Assistance Program

<u>Program in AMAs</u>

The Water Management Assistance Program (WMAP) provides financial and technical resources to assist water users in meeting their conservation requirements, facilitate renewable water supply use and obtain information about the hydrologic conditions and water availability in the AMA. The funds to support the program come from a portion of the groundwater withdrawal fees. The management plans describe the process by which the funds are allocated and how the program supports achievement of the goals and objectives of the AMA's regulatory and management programs. These funds have been used to support municipal provider toilet rebate programs, research on turf grass water needs, regional recharge planning, subsidence monitoring and many other programs.

Current fees in the AMAs that go to the WMAP range from $0.25 to $2.00 an acre-foot. Each AMA Groundwater Users Advisory Council (GUAC) makes recommendations to the director of the Department on the amount of the withdrawal fee for WMAP purposes within certain statutory limits.

<u>Potential Effect of the Active Management Practice on Basin Groundwater Supply</u>

- The WMAP would supply additional funding in support of conservation programs, aquifer monitoring and augmentation projects in the Basin. The local residents, through the GUAC, would make recommendations on the amount of the fee and how it should be allocated. If the full amount were assessed, $2.00 per acre-foot, over $50,000 would be collected annually. This program would provide benefits to the regulated water users in the Basin.

6.6 Assured Water Supply Program

6.6.1 Background

In 1973, the Arizona Legislature enacted a statewide water adequacy statute as a consumer protection measure (A.R.S. § 45-108). The law was passed in response to incidences of land fraud involving the sale of subdivision lots that were later found to have insufficient water supplies. This law requires developers to obtain a determination from the Department regarding the availability of water supplies prior to marketing new subdivision lots. When the Groundwater Code was adopted in 1980, the provisions of A.R.S. § 45-108 were amended and now apply only to subdivisions located outside of AMAs. Under A.R.S. § 45-108, the Department must evaluate a developer's water supply plans and determine whether there is an adequate water supply. The developer may also obtain a written commitment of service from a water provider that has a designation of water adequacy for its service area. The developer must provide a copy of the Department's evaluation to the State Real Estate Commissioner for disclosure to the public if water supplies are determined to be inadequate. However, the Department's evaluation does not affect whether lots may be platted or sold.

The Groundwater Code contains more rigorous provisions for new subdivisions inside the AMAs. The Code prohibits the sale or lease of subdivided land in an AMA without demonstration of an assured water supply, proof of which the developer must provide to the State Real Estate Commissioner. The AWS Program is designed to sustain the State's economic health by preserving groundwater resources and promoting long-term water supply planning. This is accomplished through regulations that require demonstration of renewable water supplies for new subdivisions. A subdivision is defined as land divided into six or more parcels where at least one parcel is less than 36 acres. Land divisions resulting in parcels larger than 36 acres are classified as "unsubdivided" lands and do not require an assured water supply determination. An assured water supply determination is required to gain approval of a subdivision plat by local governments, and to obtain authorization to sell lots by the Department of Real Estate.

In AMAs, new subdivisions are required to have a Certificate of AWS, unless a water provider with a Designation of Assured Water Supply serves them. To obtain an assured water supply determination, the statute requires a demonstration of:

- Physical, legal and continuous water availability for 100 years
- Compliance with water quality standards
- Financial capability to construct the delivery system and related features
- Consistency with the AMA's management plan
- Consistency with the AMA's management goal

Municipalities and private water companies are not required to apply for a Designation of AWS, but there are incentives to do so. A designated water provider can deliver water to new developments within their service area, without the new subdivision having to apply for their own Certificate of AWS. The most populous cities within AMAs have obtained Designations of AWS, and thus a majority of new subdivisions qualify through this process. A designation of AWS applies to current, committed and projected demands within the service area.

Physical, legal and continuous availability require the assured water supply applicant to demonstrate that there is sufficient water to meet the water demands of the service area or development for 100 years and the existence of a delivery system. They must also demonstrate ownership of the rights to all sources of water pledged towards their assured water supply demonstration.

The proposed sources of water must meet existing water quality standards. ADWR also considers the potential for poor quality water migration that could impact the applicant's water source.

Financial capability for Certificate of AWS applicants is evidenced by submittal of a Verification of Construction Assurance form signed by the appropriate platting entity. For Designations, private water companies can show approval of financing by the Arizona Corporation Commission. Cities and towns can show evidence that financing is available through a five-year capital improvement plan containing the necessary delivery, treatment and storage facilities.

Consistency with management plan for Certificate of AWS applicants requires a demonstration that the proposed uses and water demand of the proposed subdivision are efficient and in compliance with the AMA's management plan. Designation of AWS applicants must show consistency with the AMA's management plan by demonstrating that the municipal provider is in compliance with its management plan conservation requirements, or, if the provider is not yet serving water, will comply with its conservation requirements.

In safe-yield AMAs, consistency with the management goal requires the applicant to show that water demand will be met primarily with non-groundwater supplies (surface water, effluent, CAP water, groundwater imported from outside of an AMA if allowed under the groundwater transportation laws) or groundwater withdrawn pursuant to credits acquired through the extinguishment of grandfathered groundwater rights. As an alternative, in the Tucson, Phoenix and Pinal AMAs, an applicant may apply for membership in the Central Arizona Groundwater Replenishment District (CAGRD). Members of the CAGRD can continue to pump groundwater and the CAGRD will replenish that groundwater using a renewable supply somewhere in the same AMA. The CAGRD can only operate within Pima, Pinal and Maricopa Counties. AWS Rules to address consistency with the management goal requirements for the Santa Cruz AMA are being developed.

6.6.2 Potential Effect of the Active Management Practice on Basin Groundwater Supply

- The AWS Rules have the potential to impact future growth in the Basin. Existing development within the Basin would not be subject to the AWS Rules unless a water provider elected to obtain a designation of AWS. Otherwise, only new subdivisions would require an AWS Certificate. Simply put, about 8,300 acre-feet of the projected 2030 municipal demand of 27,200 acre-feet would be subject to the AWS Rules if no providers were designated and if all growth occurs in a regulated subdivision.

- The provision of the AWS Rules to utilize renewable water supplies would present a challenge to the Basin. AMAs without access to CAP water have more limited options to meet the renewable supply use requirements. Among these is to "turn off" an existing use of water to allow for a new use. The AWS Rules allow the extinguishment of grandfathered rights for AWS credits. For example, a developer could purchase a farm with an irrigation grandfathered groundwater right and extinguish the right for a credit. However, this mechanism does not normally provide for a sufficient long-term water supply for growth because the volume of available credits would likely be small and would be an expensive undertaking unless the development were located on the retired farmland.

  Effluent is a renewable supply option currently available for AWS demonstration. Effluent could be used directly, for example on a golf course or for landscape irrigation, or recharged to accumulate effluent recharge credits to offset the development's demand. Currently, effluent is being recharged to replenish the aquifer, without plans for recovery at this time. Using effluent to meet AWS replenishment requirements would mean recovering it, either within the area of hydrologic impact of the recharge, or outside the area.

  Surface water could also be used for an AWS demonstration. Surface water diversions would require a perennial source at the point of diversion or sufficient storage, backup supplies or a drought response plan. If there is no backup supply, the volume determined by the director to be annually available is limited to 120% of the minimum annual diversion for the period of record. In addition to demonstrating a physical supply, the applicant must have a certificated water right, a decreed water right or a pre-1919 claim to the water and have used the water within the past five years. The applicant must also submit evidence that the actual supply available matches the legal availability of the right or claim.

  While transportation of CAP water to the Basin has been proposed, availability of CAP water is limited and the cost of a CAP pipeline to the Basin would be substantial. Estimates generated for the Upper San Pedro Partnership are $121.7 million for construction of a pipeline and $16.4 million in annual costs (Fluid Solutions and BBC Research and Consulting, 2002).

- There are provisions in the AWS Rules regarding transportation of groundwater from outside an AMA for AWS purposes. However, transportation can only be made from those basins specifically identified in the Groundwater Code (see section 6.7).

- In the absence of sufficient renewable water supplies, the AWS Rules could limit new subdivision development.

- If AWS rules were put in place, the cost of development would increase. Costs would include hydrologic studies, application costs, and utilization of renewable supplies. Renewable supply utilization, which may require purchase, conveyance and extensive treatment, is typically more expensive than pumping groundwater.

  In many communities, developers and municipal water providers charge a water development fee for new developments. This fee increases the cost of a new home to offset the cost of constructing infrastructure, bringing in a renewable supply, or recharging water to offset the water demand of the proposed subdivision. In the Phoenix, Pinal and Tucson AMAs, developments that are members of the CAGRD also have a tax imposed on the volume of water each parcel uses. Alternatively, the replenishment cost may result in an increase in water rates in cases where water provider service areas are members of the CAGRD.

6.7 Transportation of Groundwater

6.7.1 Background

The state is divided into hydrologic groundwater basins and sub-basins within some of those basins. These groundwater basins and sub-basins do not necessarily correspond with surface watersheds and subwatersheds. This is due in part to subsurface geology that can impact groundwater flow and cause it to vary from surface water drainage patterns. Groundwater transportation laws pertain to groundwater basins and sub-basins and not to surface watersheds and subwatersheds.

Statutes governing the transportation of groundwater within and between basins are designed to protect hydrologically distinct sources of groundwater supplies and the economies in rural areas by ensuring the groundwater is not depleted in one groundwater basin to benefit another. In general, groundwater cannot be transported between groundwater basins or from a groundwater basin outside an AMA into an AMA except for certain transfers specified in statute. A.R.S. §§ 45-544 and 45-551 through 45-555.

Under current statute, groundwater can legally be transported within a sub-basin, or within a basin that has not been divided into sub-basins, without payment of damages. A.R.S. § 45-541 and A.R.S. § 45-544. Groundwater may also be transported between sub-basins in the same basin. Transportation of groundwater between sub-basins would be subject to payment of damages if the groundwater is withdrawn pursuant to a Type 2 non-irrigation right, a service area right, a groundwater withdrawal permit or from an exempt well. A.R.S. §§ 45-542 through 45-545.

6.7.2 Potential Effect of the Active Management Practice on Basin Groundwater Supply

- The current statutes would not allow the transportation of groundwater into the Basin if it were an AMA. Even outside of AMAs, the statutes generally do not allow groundwater to be transported from one basin to another, but only between sub-basins in the same basin. Thus the effect of the current groundwater transportation statute on the Upper San Pedro Basin would be the same whether the Basin becomes an AMA or not; groundwater cannot be transported into the Upper San Pedro Basin from another basin without a change in the law.

- Attempting to change the law to allow importation of groundwater could face political challenges, as well as present physical, economic, environmental, and legal obstacles. Adjacent groundwater basins include the Willcox, Douglas, Lower San Pedro, Cienega Creek, and San Rafael Basins.

- If the Basin were an AMA, groundwater withdrawn in the Basin could be transported to any location within the Basin. However, transportation of groundwater between the Allen Flat sub-basin and the Sierra Vista sub-basin would be subject to payment of damages, which means any person alleging injury as a result of the groundwater transportation could bring a civil action against the person transporting the groundwater to recover damages for the injury. In such an action, neither injury to nor impairment of the water supply of the person alleging injury would be presumed from the fact of transportation. A.R.S. § 45-545.

6.8 Summary

The water management practices discussed in this Chapter are statutorily identified and intended to provide the tools to address groundwater depletion conditions in existing AMAs. Effective water management must have a long-term perspective, a management goal or goals, and be regional in scope. This is an advantage of having a regulatory planning framework such as a series of management plans as required for AMAs.

A key component of water management planning is access to accurate water use information over a meaningful period of time. Comprehensive water measurement and data collection is not done in a consistent way in the USP Basin, hindering understanding of water resource conditions. This impacts the ability to track water use trends, determine the influence of weather, measure the success of water conservation programs, calculate system losses, and determine whether water is being used efficiently. Within AMAs, mandatory annual water use monitoring and reporting by water rightholders provides long-term, consistent data essential to making informed water management decisions and to measure progress toward reaching water management goals.

AMA practices apply to groundwater use. Entities that do not use any groundwater are not regulated with the exception that the prohibition on irrigating new lands applies to all water sources. AMA practices are generally voluntarily implemented on federal lands but are not directly required. In AMAs, irrigation of less than 10 acres of land is not subject to conservation requirements and domestic wells are unregulated. Federal, domestic well and small acreage water use, stock watering and facilities using 100% effluent account for about 27 percent of the total USP Basin demand that would not be regulated if the Basin were designated as an AMA.

A number of water management practices have been implemented in the USP Basin and additional ones are planned. These include groundwater recharge, direct effluent use, water conservation ordinances and municipal conservation programs. The Upper San Pedro Partnership has adopted an annually updated water resource conservation plan for the Sierra Vista portion of the Basin. In addition, beginning in 2004, the Partnership must annually prepare a report on water use management and conservation measures that have been implemented and are needed to restore and maintain the sustainable yield of the regional aquifer by September 30, 2011 (Public Law 108-136; see Chapter 2.).

In the absence of a groundwater rights system, there are no restrictions on future groundwater withdrawals by non-exempt wells. New non-exempt wells can be drilled without undergoing a well impact analysis. Within AMAs, a groundwater rights system caps agricultural water use at a historic level and new agricultural lands cannot be brought into production. In the USP Basin, agricultural expansion does not appear to be an issue at this time. In fact, there have been substantial declines in agricultural acreage since 1985. In AMAs industrial uses (served by industrial facility wells) are also essentially limited, however industrial use permits may be issued if no other source of water is available. Municipal uses can increase through service area rights, which are not capped but are subject to conservation requirements. Since there is already an active conservation program in the Basin, particularly in the Sierra Vista sub-area, and per capita use appears to be in line with water use in AMAs, additional conservation by the municipal sector may be limited.

A critical water management tool in the AMAs is the AWS program. Its renewable supply use component has been a major impetus to utilization of renewable supplies in the Pinal, Tucson and Phoenix AMAs. Where renewable supplies are limited, other strategies need to be explored such as extinguishment of water rights or other offsets to groundwater pumping.

Many areas of the state faced with drought and limits on long-term water supplies are looking towards more expensive and complex water augmentation strategies. These include transfers of Colorado River water to distant basins and, if allowed by statute, transportation of groundwater from other basins. Plans of this nature must overcome significant political, legal, environmental and economic obstacles. Appendix M summarizes the detailed discussions of AMA practices in this chapter and their potential effect on groundwater supply in the USP Basin.

CHAPTER 7

SUMMARY OF FINDINGS, DIRECTOR'S DETERMINATION AND RECOMMENDATIONS

This Chapter summarizes the findings from this report and presents the director's determination of whether the Upper San Pedro Basin should be designated as an AMA based on the statutory criteria in A.R.S. § 45-412(A). Also included are the Department's recommendations on water management, hydrologic investigation and monitoring activities for the Basin.

Under A.R.S § 45-412(C), ADWR must "periodically review all areas which are not included within an active management area to determine whether such areas meet any of the criteria for active management areas…". The criteria are specific. The director may propose to designate a subsequent AMA if the director determines that any of the following criteria are met: 1) active management practices are necessary to preserve the existing supply of groundwater for future needs; 2) land subsidence or fissuring is endangering property or potential groundwater storage capacity; and 3) use of groundwater is resulting in actual or threatened water quality degradation. A.R.S. § 45-412(A). The area proposed for designation may not be smaller than a groundwater basin, except for the regional aquifer systems of northern Arizona. A.R.S. § 45-412(B).

The USP Basin boundaries are defined by ADWR as "the surface watershed of the San Pedro River from the Republic of Mexico downstream to the area referred to as "The Narrows" north of Benson, and in addition, the upper drainage areas of Hot Springs and Kelsey Canyons which enter the San Pedro River north of "The Narrows." The USP Basin is divided into two sub-basins: the Allen Flat sub-basin and the Sierra Vista sub-basin, (Arizona Department of Water Resources, 1982). See Figure 2-1 for an overview of the USP Basin.

For the purposes of this report, the Department divided the USP Basin into the "Sierra Vista sub-area" and the "Benson sub-area." These informal divisions were created by the Department to allow water use by sectors (primarily municipal and agricultural) to be discussed by geographic location. The Sierra Vista sub-area includes the portion of the USP Basin from the U.S. Mexico border to Fairbank. The Benson sub-area extends from Fairbank to "The Narrows," including the Allen Flat sub-basin (see Figure 3-2).

7.1 Summary of Findings

Since the Department's previous review of the USP Basin for potential AMA designation (Putman and others, 1988), and the recommendation not to designate the Basin, there has been considerable hydrologic research in the Sierra Vista sub-area. These new studies and groundwater level data collected throughout the Basin are described in Chapters 2 and 5 and have increased the Department's understanding of Basin hydrology and revealed a number of new conditions. Also, there has been an increase in the demand for water resources and additional water supply management activity in the USP Basin since the last report. These changes are summarized below.

Among the new data is a finding of a significant decrease in the previous estimate of groundwater in storage. As discussed in Chapter 3 of this report, a 1999 USGS study estimated that the thickness of the alluvial fill, which represents the regional aquifer in the Sierra Vista sub-basin, is shallower on average than previously estimated in 1988. In this report, ADWR used the USGS information and lower specific yield estimates to generate a new estimate of groundwater in storage of 20 to 26 million acre-feet in the regional and floodplain aquifer. Total groundwater in storage had previously been estimated by ADWR at about 41 to 48 million acre-feet (San Pedro HSR, 1991a and Putman and others, 1988). Although the estimate is about half that previously estimated, there are still considerable groundwater resources available in the Basin. This is supported by water level measurements in wells, which generally show flat or slowly declining water levels in most areas, and water level rises in some areas.

The artesian heads present in some portions of the regional aquifer underlying the floodplain alluvium of the San Pedro River have decreased somewhat over time due to groundwater development in these areas. In the Benson-Pomerene area, Barnes and Putman (2004) reported a modest water-level decline in the deeper (artesian) aquifer. The shallow floodplain aquifer, which underlies the San Pedro River, has shown no long-term declines in water level.

Between 1990 and 2001, the Fort Huachuca/Sierra Vista cone of depression deepened slightly, but rates of water level decline are less than those reported by Putman and others (1988). Since the previous study, two new cones of depression are forming in the USP Basin in addition to the Fort Huachuca/Sierra Vista cone. The newly identified cones are relatively minor in comparison. One is associated with the Bisbee wellfield and the other with pumping in the Benson area. The Bisbee cone is developing due to a reduction in incidental recharge from the Bisbee mine operations.

There are also natural influences on the Basin's groundwater resources. A shift in summer and winter rainfall patterns have brought less summer rainfall, and drought may have contributed to groundwater level declines in some areas. There has been an increase in the amount of riparian vegetation in the San Pedro Riparian National Conservation Area (SPRNCA) due to the removal of agricultural and grazing activities, although there is likely a net decrease in overall demand from historical agricultural usage levels.

In addition, the USP Basin groundwater resources are impacted by activities within the portion of the Basin that extends into Mexico. There are concerns about existing and expanding agricultural and mining activities in the Cananea, Sonora area although the extent of the potential impact is not fully understood.

A groundwater budget, an accounting of aquifer inflows and outflows, was developed for this report. Major inflows to the groundwater system come from recharge of water along the mountain fronts (including ephemeral channel recharge), groundwater flowing across the Mexican Border, and recharge of flood flows of the streams in the Basin. Secondary sources are recharge of water from recharge projects, septic tanks, and golf courses. Outflows include demand by the water use sectors and riparian vegetation, and baseflow and underflow between sub-areas and out of the Basin. The difference between inflows and outflows results in a change in groundwater in storage. In 2002, it is estimated that outflows exceeded inflows resulting in a Basin storage deficit of -9,500 acre-feet; approximately -8,350 acre-feet in the Sierra Vista sub-area and -1,320 acre-feet in the Benson sub-area. Note that the Basin total is not equal to the sum of the sub-basin totals due to intra-basin transfers.

Cultural water demand and supply was evaluated in Chapter 4. The primary water demand sectors in the Basin are municipal and agricultural water users. A relatively small volume of water demand is attributable to industrial users. In 2002, municipal demand was the largest water use sector in the Basin at 18,800 acre-feet of which 13,700 acre-feet did not return to the aquifer through incidental or artificial recharge (net use groundwater). Agricultural consumptive use was 9,800 acre-feet and industrial sector use was 2,100 acre-feet of which 2,000 acre-feet was net use groundwater.

Since 1985, there has been a significant shift in demand from agricultural water use to municipal water use, and this trend is projected to continue as population increases. The agricultural demand decline of over 40% between 1985 and 2002 is attributable to several factors. These factors include creation of the SPRNCA and associated cessation of agricultural activities, purchase of agricultural lands to establish conservation easements that reduce irrigation and other pumping near the San Pedro River, subdivision of agricultural lands and economic factors. By 2030, the Basin population is projected to increase to 110,000 and total demand to 40,000 acre-feet, of which 26,900 acre-feet is projected to be net use groundwater.

There has been an increase in demand and supply management activity in the USP Basin since the previous study. Effluent is being further utilized for golf course irrigation and is also being recharged at two locations between pumping centers and the San Pedro River. Stormwater recharge projects have been constructed at Fort Huachuca. Implementation of conservation measures has influenced water demand in the Basin. Fort Huachuca has reduced its use by almost 45% between 1993 and 2002 due to irrigation efficiency, installation of low water use plumbing fixtures, replacement of high water use landscaping and education. Water conservation programs and ordinances have been implemented in the Sierra Vista area but as population has increased, so has water use. Municipal demand has increased by over 5,000 acre-feet between 1985 and 2002 and the basin-wide per capita rate has not changed appreciably.

The Department reviewed past predictive studies of the Basin and compared them to the Department's recent findings (Chapter 5). This review demonstrates that caution must be exercised when utilizing model results since all of the studies reviewed made one or more predictions that differ substantially from current conditions.

The potential effect of AMA practices on the Basin groundwater supply was evaluated in detail in Chapter 6. These practices include a groundwater rights system that restricts groundwater withdrawals, prohibits the development of new irrigated farmland, requires that new subdivisions have long-term dependable water supplies, requires that groundwater withdrawals be measured and reported, requires mandatory conservation for agricultural, municipal and industrial users, and develops management plans to achieve the management goal. AMA practices, however, would not affect all water users, would not prohibit growth, and would not significantly restrict current groundwater use. In the USP Basin approximately 27% of the current water demand would not be subject to AMA practices. Municipal per capita conservation requirements would apply to approximately 47% of the municipal water demand in the Basin. Total municipal water demand could increase as the population increased and new water service areas could be formed. Because water providers in AMAs are not required to demonstrate an assured water supply for their existing water service area, an assured water supply program would likely apply only to new subdivisions.

The occurrence of land subsidence or fissuring in the Basin was also investigated for this report (see Chapter 3). The two primary factors controlling whether subsidence will occur are the magnitude of the water table change and the percentage of fine-grained material (clays/silt) within the aquifer system. The potential for land subsidence exists within the Basin if these conditions are met. However, there are no known documented occurrences of land subsidence caused by aquifer system compaction and subsidence does not seem likely for most portions of the Basin given the comparatively small water-level changes from pre-development conditions.

In addition, the Department evaluated water quality data for the Basin as discussed in Chapter 3, to determine if actual or threatened water quality degradation resulting from use of groundwater was occurring. Contamination from mining, municipal, industrial, military, and commercial activities has occurred in the Basin and could potentially threaten groundwater resources, however, the threats are localized and are being addressed through local, state and federal efforts.

7.2 Director's Determination

Following is the director's determination on whether to propose to designate the USP Basin as a subsequent active management area pursuant to the criteria in A.R.S. § 45-412(A), based on the Department's findings.

Criteria 1: Are active management practices necessary to preserve the existing supply of groundwater for future needs?

Because there are sufficient groundwater supplies in the USP Basin to meet the future needs of municipal, industrial and agricultural water users, the director has determined that AMA practices are not necessary.

Criteria 2: Is land subsidence or fissuring endangering property or potential groundwater storage capacity?

Based on the hydrogeology and studies of the Basin, the director has determined that there is no evidence that land subsidence or fissuring is endangering property or potential groundwater storage capacity in the USP Basin.

Criteria 3: Is use of groundwater resulting in actual or threatened water quality degradation?

Based on an evaluation of water quality data, the director has determined that the use of groundwater is not resulting in actual or threatened water quality degradation in the USP Basin.

Because the director has determined that none of the statutory criteria have been satisfied, the director does not propose to designate the USP Basin as an active management area at this time.

7.3 Recommendations

Although the director has determined that the statutory criteria for designating the Basin as an AMA do not presently exist, the Department recognizes the need for water management and continued hydrologic investigation and monitoring in the Basin. The following section discusses the Department's recommendations.

- The Department will continue to measure groundwater levels in the Basin. Groundwater level measurement locations should recognize expected development patterns in the Basin to the extent possible. Cooperation of local governments, water companies, and residents is vital in this effort.

- A cooperative water-level measurement program should be developed to cover the San Pedro drainage area between Cananea, Sonora and "The Narrows," north of Benson. Annual groundwater withdrawal data and information about groundwater use in the Mexican portion of the Basin would be useful in understanding the entire San Pedro Basin.

- Riparian water use and mountain front recharge in the USP Basin are among the largest and least certain components of the water budget, particularly for the Benson sub-area. Research to determine the water needs of the riparian community should be continued. Research should also include groundwater level monitoring in the floodplain aquifer and the underlying regional aquifer, as well as studies to better quantify mountain front recharge.

- The Benson sub-area has received less scientific attention than the Sierra Vista sub-area. More research focusing on hydrologic processes in this part of the USP Basin is encouraged.

- The USGS streamflow gaging stations within the USP Basin should be continued. The feasibility of re-installing a gaging station at “The Narrows” should be investigated to provide a measure of Basin outflows and to permit construction of a more accurate water budget.

- Groundwater models, together with updated water demand and supply information, may be used to guide basin-wide water management decisions. Assumptions regarding water demands and recharge should continue to receive rigorous scrutiny when evaluating model results.

- Water conservation efforts and implementation of recharge projects have positive benefits in reducing groundwater overdraft as indicated by modeling studies and by recent data collected by the Department. Such local efforts should be continued throughout the Basin.

- The Department will continue to work with the Upper San Pedro Partnership as a Partnership member on local water management and planning efforts. These efforts should be continued and supported at the local, state and federal level.

- The Department will facilitate the Upper San Pedro Partnership’s efforts to attain its sustainable yield goal under Section 321 of the National Defense Authorization Act of 2004 and will work with the Partnership to identify the role the State may play in support of this effort.

- The Benson sub-area is projected to experience population growth with three master-planned communities proposed in the sub-area. ADWR should encourage and provide technical and planning support to Benson-area stakeholder water management efforts.

- Area watershed groups should investigate sources of alternative water supplies for the Basin as a long-term water management strategy.

- Metering and consistent annual reporting of water demands by all large water users in the Basin would provide a more accurate source of data for planning and monitoring purposes. This option should be explored by local stakeholders and ADWR.

- Well spacing criteria could provide hydrologic benefits by managing the location of new pumping in some areas. This option should be explored by ADWR and local stakeholders.

- The Department will provide support to local stakeholders for legislative changes to facilitate those water management efforts considered necessary by local stakeholders and ADWR.

Although the director does not propose to designate the Basin as an AMA at this time, the Department believes that the recommendations described above provide useful water management tools for the future. The Department will continue to work at the local, state and federal levels to promote solutions to water management issues in the Basin.

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CHAPTER 8

REFERENCES

Aggregates Manager, 2001,Vol. 5, no.11, pg.77, February 2001.

American Water Works Association, 1999, Residential End Uses of Water

Anderson, T.W. and Freethey, G.W., 1994, Simulation of Ground-Water Flow in Alluvial Basins in South-Central Arizona and Parts of Adjacent States. U.S. Geological Survey Professional Paper 1406-D.

Arizona Corporation Commission, Utilities Division, 2001, File Data on 2000 Annual Utility Reports for Water Companies.

Arizona Corporation Commission, Utilities Division, 2003, File Data on 2002 Annual Utility Reports for Water Companies.

Arizona Department of Commerce, 2004a, Benson Community Profile, June.

Arizona Department of Commerce, 2004b, Sierra Vista Community Profile, April.

Arizona Department of Economic Security, Population Statistics Unit, 2002, Population Projections for State of Arizona.

Arizona Department of Environmental Quality, 2000, Assessment & Monitoring: 305(b) Reports, San Pedro-Willcox Playa–Rio Yaqui Watershed Fact Sheet and Tables, June 2000. http://www.adeq.state.az.us/environ/water/assess/305/index.html

Arizona Department of Environmental Quality, 2003a, Arsenic Master Plan, Executive Summary, February 2003, EQR 03-02.

Arizona Department of Environmental Quality, 2003b, Waste Programs Division: Superfund Programs: Site Info: Statewide Area Sites. http://www.adeq.state.az.us/environ/waste/sps/statesites.html#apchpdra

Arizona Department of Environmental Quality, 2003c, Leaking Underground Storage Tank (LUST) List. http://www.adeq.state.az.us/environ/waste/ust/guide.html

Arizona Department of Environmental Quality, 2004, Database of arsenic concentrations reported by public water systems in Arizona; query performed on September 27, 2004.

Arizona Department of Water Resources, 1982, Groundwater Basin and Sub-basin Designations.

Arizona Department of Water Resources, 1991a, Hydrographic Survey Report for the San Pedro River Watershed. Volume 1: General Assessment.

Arizona Department of Water Resources, 1991b, Hydrographic Survey Report for the San Pedro River Watershed. Volume 3: Sierra Vista Subwatershed Watershed File Reports.

Arizona Department of Water Resources, 1991c, Tucson AMA Second Management Plan, 1990-2000.

Arizona Department of Water Resources, 1993, ADWR Population Projections (1990-2040) for use in Statewide Water Planning: Based on May 1993 POPTAC Recommended DES Approved Population Projections, August.

Arizona Department of Water Resources, 1997, ADWR Population Projections (1997-2050) for use in Statewide Water Planning: Based on May 1993 POPTAC Recommended DES Approved Population Projections, September.

Arizona Department of Water Resources, 1999a, Santa Cruz AMA Third Management Plan, 2000-2010.

Arizona Department of Water Resources, 1999b, Tucson AMA Third Management Plan, 2000-2010.

Arizona Department of Water Resources, 2002a, Verde River Watershed Study.

Arizona Department of Water Resources, 2002b, Groundwater Site Inventory (GWSI).

Arizona Department of Water Resources, 2002c, Well Registration Files.

Arizona Department of Water Resources, Hydrology Division, May 2004, unpublished analysis.

Arizona Geological Survey, 2000, Digital Spatial Data for the Geologic Map of Arizona. Digital Information Series 08, Version 3.0.

Arizona Regional Image Archive, 2004, http://aria.arizona.edu

Arizona Revised Statutes, 2004-2005, Volume 15, Titles 45 & 46.

Arizona Sand and Gravel Operations, Aggregates Manager, Vol.5, #11, pg. 77, February 2001.

Arizona State Land Department, 1997, Arizona Stream Navigability Study for the San Pedro River: Gila River Confluence to the Mexican Border. Prepared by Ch2M Hill, SWCA Environmental Consultants, and the Arizona Geological Survey; revised by JE Fuller/Hydrology and Geomorphology, Inc.

Arizona State University, 1975, Evaporation and Evapotranspiration (Maps), Laboratory of Climatology, Arizona Resources Information System Cooperative Publication No. 5.

Arizona Water Commission, 1975, Arizona State Water Plan, Phase I, Inventory of Resources and Uses.

Barnes, R.L., 1997, Maps Showing Groundwater Conditions in the Upper San Pedro Basin, Cochise, Graham, and Santa Cruz Counties, Arizona – 1990. Department of Water Resources Hydrologic Map Series Report Number 31.

Barnes, R.L. and Putman, F., 2004, Maps Showing Groundwater Conditions in the Upper San Pedro Basin, Cochise, Graham, and Santa Cruz Counties, Arizona – 2001-2002. Department of Water Resources Hydrologic Map Series Report Number 34.

Brown, D.E., 1982, Biotic Communities of the American Southwest-United States and Mexico. Desert Plants 4(1-4). University of Arizona.

Brown, S.G., Davidson, E.S., Kister, L.R., and Thomsen, B.W., 1966, Water Resources of the Fort Huachuca Military Reservation, Southeastern Arizona. U.S. Geological Survey Water-Supply Paper 1819-D.

Brown, D. E. and Lowe, C.H., 1978, Biotic Communities of the Southwest. USDA Forest Service, General Technical Report RM-41, Map.

Bryan, K., Smith, G.E., and Waring, G.A., 1934, Groundwater Supplies and Irrigation in San Pedro Valley, Arizona. U.S. Geological Survey Open File Report.

Burtell, R.T., 1989, Geochemistry and Occurrence of Ground Water in the Allen Flat Basin, Arizona. M.S. Thesis, University of Arizona, Tucson.

Chehbouni, A., Goodrich, D.C., Moran, M.S., Watts, C.J., Kerr, Y.H., Dedlieu, G., Kepner, W.G., Shuttleworth, W.J., and Sorooshian, S., 2000, A Preliminary Synthesis of Major Scientific Results During the SALSA Program.

Coes, A.L., Gellenbeck, D.J., and Towne, D.C., 1999. Ground-Water Quality in the Sierra Vista Subbasin, Arizona, 1996-1997. U.S. Geological Survey Water-Resources Investigations Report 99-4056.

Commission for Environmental Cooperation, 1999, Sustaining and Enhancing Riparian Migratory Bird Habitation on the Upper San Pedro River. Prepared for the Secretariat of the Commission for Environmental Cooperation. Prepared by Rojo, H.A., Bredehoeft, J., Lasewell, R., Price, J., Stromberg, J., and Thomas, G.A., 123pp.

Corell, S.W., Corkhill, F. Lovvik, D. and Putman, F., 1996. A Groundwater Flow Model of the Sierra Vista Subwatershed of the Upper San Pedro Basin, - Southeastern Arizona. Arizona Department of Water Resources Modeling Report No. 10.

Corell, S.W., 1996, Groundwater Flow Model Scenarios of Future Groundwater and Surface Water Conditions: Sierra Vista Subwatershed of the Upper San Pedro Basin, - Southeastern Arizona. Supplement to Arizona Department of Water Resources Modeling Report No. 10.

Cordy, G.E., Gellenbeck, D.J., Gebler, J.B., Anning, D.W., Coes, A.L., Edmonds, R.J., Rees, J.A.H., Sanger, H.W., 2000. Water Quality in the Central Arizona Basins, Arizona, 1995-1998. U.S. Geological Survey Circular 1213.

Dahm, C.N. Cleverly, J.R., Allred Coonrod, J.E., Thibault, J.R., McDonnell, D.E., and Gilroy, D.J., 2002, Evapotranspiration at the land/water interface in a semi-arid drainage basin, Freshwater Biology, 47, 831-843.

Davis, S.N. and DeWiest, R.J., 1966, Hydrogeology. John Wiley & Sons, Inc.

Drewes, H., 1974, Geology Map and Sections of the Happy Valley Quadrangle, Cochise County, Arizona, USGS Miscellaneous Investigations Series I-832.

Drewes, H., 1980, Tectonic Map of Southeast Arizona. U.S. Geological Survey Miscellaneous Investigation Series Map 1-1109.

Evans, D.W., 2001, Recharge Monitoring Techniques in the Sierra Vista Southeastern Arizona. Paper presented at the 10th Biennial Symposium on the Artificial Recharge of Groundwater, Tucson, AZ, June 7-9, 2001.

Fetter, C.W., 1994, Applied Hydrogeology. 3rd ed., Prentiss-Hall.

Fluid Solutions, 2000, Groundwater and the City of Benson. Prepared for the City of Benson.

Fluid Solutions and BBC Research & Consulting, 2002, SP-0002: Reduce Water Consumption/Reclaim Water Resources. Phase 2 Report: Feasibility and Cost Analysis for Selected Alternatives. Prepared for the Upper San Pedro Partnership.

Freethey, G.W., 1982, Hydrologic Analysis of the Upper San Pedro Basin from the Mexico-U.S. Boundary to Fairbank, Arizona. U.S. Geological Survey Open File Report, 82-752.

Freethey, G.W. and Anderson, T.W., 1986, Predevelopment Hydrologic Conditions in the Alluvial Basins of Arizona and Adjacent Parts of California and New Mexico. U.S. Geological Survey Hydrologic Investigations Atlas HA-664, Sheet 3 of 3.

Gettings, M.E., and Houser, B.B., 2000, Depth to Bedrock in the Upper San Pedro Valley, Cochise County, Southeastern Arizona. USGS Open File Report 00-138.

Goode, T.C., and Maddock, T., 2000, Simulation of Groundwater Conditions in the Upper San Pedro Basin for the Evaluation of Alternative Futures. Department of Hydrology and Water Resources, and University of Arizona Research Laboratory for Riparian Study, University of Arizona.

Goodrich, D.C., and others, 1999, Preface Paper to the Semi-arid Land Surface/Atmosphere (SALSA) Issue. Program Special Issue.

Graf, C.G, 1999, Hydrogeology of Kartchner Caverns State Park, Arizona. Journal of Cave and Karst Studies, August, pp 59-67, 1999.

Halverson, P.H., 1984, An Exploratory Gravity Survey in the Upper San Pedro Valley, Southeastern Arizona: University of Arizona, M.S. Thesis.

Heindl, L.A., 1952, Upper San Pedro Basin, Cochise County, in Halpenny, L.D., Groundwater in the Gila River Basin and Adjacent Areas, Arizona - A Summary. U.S. Geological Survey Open File Report No. 29.

Hereford, R., 1993, Entrenchment and Widening of the Upper San Pedro River, Arizona. The Geological Society of America, Special Paper 282.

Jahnke, P., 1994, Modeling of Groundwater Flow and Surface Water/Groundwater Interaction for the San Pedro River from Fairbank to Redington, Arizona. M.S. Thesis, Department of Hydrology, University of Arizona, Tucson Arizona.

Konieczki, A.D., 1980, Maps Showing Groundwater Conditions in the Upper San Pedro Basin Area, Pima, Santa Cruz, and Cochise Counties, Arizona- 1978. U.S. Geological Survey Open File Report 80-1192.

Lee, W.T., 1905, Notes on the Underground Water of the San Pedro Valley, Arizona. U.S. 58th Congress, 3rd Session, House Document 28, 2nd Edition, Washington, D.C.

McCormick and others, 2002, Water Resources Data Arizona, Water Year 2001, U.S. Geological Survey Water-Data Report AZ-01-1.

National Research Council, 1991, Mitigating Losses from Land Subsidence in the United States. National Academy Press, Washington D.C.

Officer, J.E., 1987, Hispanic Arizona, 1536-1856, University of Arizona Press, Tucson.

Oppenheimer, J.M. and Sumner, J.S., 1980, Depth-to Bedrock Map, Basin and Range Province, Arizona. Tucson, Laboratory of Geophysics, University of Arizona, Tucson (scale 1:1,0000.000).

Pattie, J.O., 1831,The Personal Narrative of James O. Pattie. J.B. Lippencott Co., New York in NSC, 1993.

Pool, D.R. and Coes, A.L., 1999. Hydrogeologic Investigations of the Sierra Vista Subwatershed of the Upper San Pedro Basin, Cochise County, Southeast Arizona. U.S. Geological Survey Water-Resources Investigations Report 99-4197.

Putman, F., Mitchell, K., and Bushner, G., 1988, Water Resources of the Upper San Pedro Basin, Arizona. Arizona Department of Water Resources.

Roeske, R.H., and Werrell, W.H., 1973, Hydrologic Conditions in the San Pedro River Valley, Arizona, 1971. Arizona Water Commission Bulletin 4. Prepared by the U.S. Geological Survey.

SAVCI Engineering Technology, 1998, Groundwater Flow and Transport Model Report, CTSA Project Area, Bisbee, AZ. Prepared for Phelps-Dodge Mining Company.

Schwartzman, P.N., 1990, A Hydrogeologic Resources Assessment of the Lower Babocomari Watershed, Arizona, M. S. Thesis submitted to Department of Hydrology and Water Resources, University of Arizona.

Scott, P.S., MacNish, R.D., and Maddock III, T., 1996, Effluent Recharge to the Upper Santa Cruz River Floodplain Aquifer, Santa Cruz County, Arizona. Arizona Research Laboratory for Riparian Studies, University of Arizona, Tucson.

Scott, R.L., Goodrich, D.C., Levick, L., McGuire, R. and Cable W., 2004, Final Report Draft of San Pedro Riparian National Conservation Area (SPRNCA) Water Needs Study, with contributions by USDA-ARS, University of Wyoming, and the University of Arizona; preliminary study subject to change.

Sellers, W.D., and Hill, R., 1974, Arizona Climate 1931-1972. University of Arizona Press.

Sierra Vista Herald, 2003, Newspaper article entitled, "Partnership shows off its efforts: City of Bisbee playing role to protect basin ", April 30, 2003.

Snyder, K.A., And Williams, D.G., 2000, Water Sources Used by Riparian Tree Varies Among Stream Types on the San Pedro River, Arizona. Special Issue of the Journal of Agricultural and Forestry Meteorology, June, 2000.

Strange, W.E., 1984, Subsidence Monitoring for the State of Arizona, National Geodetic Survey, U.S. Department of Commerce, Rockville, MD.

The Indicator, Cochise College Center for Economic Research, 2003, Vol. 4, no.1, pg. 8, Winter 2003.

Thompson, T.H., Nuter, J., and Anderson, T.W., 1984, Maps Showing Distribution of Dissolved Solids and Dominant Chemical Types in Ground Water, Basin and Range Province, Arizona. U.S. Geological Survey Water-Resources Investigations Report 83-4114-C.

U.S. Army, 2000, Fort Huachuca ESA Compliance Aerial Photo Analysis of the San Pedro and Babocomari Rivers.

U.S. Army, 2002, Programmatic Biological Assessment for Ongoing and Programmed Future Military Operations and Activities at Fort Huachuca, Arizona. Environmental and Natural Resources Division, Directorate of Installation Support, U.S. Army Garrison, Fort Huachuca, Arizona, July.

U.S. Bureau of Reclamation, 1993, Central Arizona Project M & I Water Supply Pipeline for Sierra Vista and Fort Huachuca, Arizona: Appraisal Designs and Cost Estimates, November.

U.S. Census Bureau, 1990 Census Summary File (SF1) General Population and Housing Characteristics.

U.S. Census Bureau, 2000 Census Summary File (SF1) General Population and Housing Characteristics.

U.S. Environmental Protection Agency, 2003, City of Bisbee Wastewater System Improvements Project Environmental Assessment.

U.S. Fish and Wildlife Service, 2002, National Wetlands Inventory, San Pedro River Wetland/Riparian Project, August, 2002-CD.

U.S. Geological Survey, 1968-72, Water Resources Data for Arizona, 1968-72-Part 1. Surface Water Records.

U.S. Geological Survey, 1986, Upper San Pedro Basin Ground-Water Summaries for 1966 through 1985. Unpublished data on file in Tucson office of U.S.G.S., Water Resources Division.

U.S. Geological Survey, 2004a, Water Management of the Regional Aquifer in the Sierra Vista Subwatershed, Arizona - 2004 Report to Congress. Draft report prepared in consultation with the Secretaries of Agriculture and Defense and in cooperation with the Upper San Pedro Partnership in response to Public Law 108-136, Section 321.

U.S. Geological Survey, 2004b, http://www.water.usgs.gov

U.S. Geological Survey, 1999, Land Subsidence in the United States. U.S. Geological Survey Circular 1182, edited by D. Galloway, D.R. Jones, and S.E. Ingebritsen.

Vionnet, L.B., and Maddock III, T., 1992, Modeling of Ground-water Flows and Surface/Groundwater Interaction for the San Pedro Basin – Part 1 – Mexican Border to Fairbank, AZ. Department of Hydrology and Water Resources, University of Arizona, Tucson, AZ, HWR No. 92-010.

W&EST, Inc. (Water and Environmental Systems Technology, Inc.), 1996. Upper San Pedro Basin Model, Progress Report to Gila River Indian Community. Report to the Gila River Indian Community, Sacaton, Arizona.

Walton, W., 1970, Groundwater Resource Evaluation. McGraw-Hill.

Waters, M.R., and Haynes, C.V., 2001, Late Quaternary Arroyo Formation and Climate Change in the American Southwest in Geology, May 2001; v. 29, no. 5, pp. 339-402.

Western Regional Climate Center (WRCC), 2003, http://www.wrcc.dri.edu